

- [54] **METHODS FOR DIGITALLY NOISE AVERAGING AND ILLUMINATION EQUALIZING FINGERPRINT IMAGES**
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- [21] **Appl. No.:** 20,331
- [22] **Filed:** Feb. 27, 1987
- [51] **Int. Cl.⁴** G06K 9/00; G06K 9/56
- [52] **U.S. Cl.** 382/52; 382/4; 382/54; 358/163
- [58] **Field of Search** 382/4, 5, 52, 54; 358/163, 166

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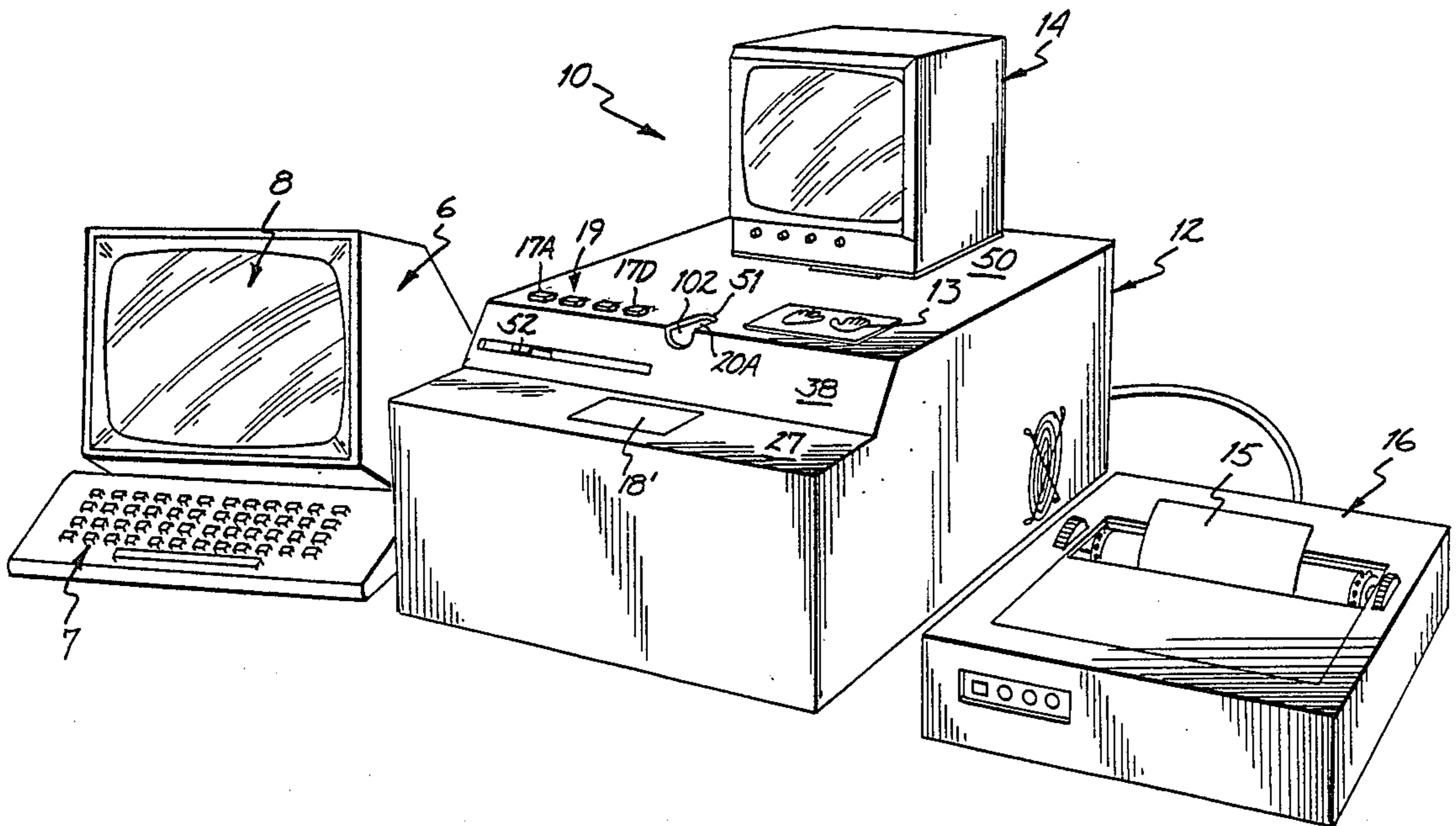
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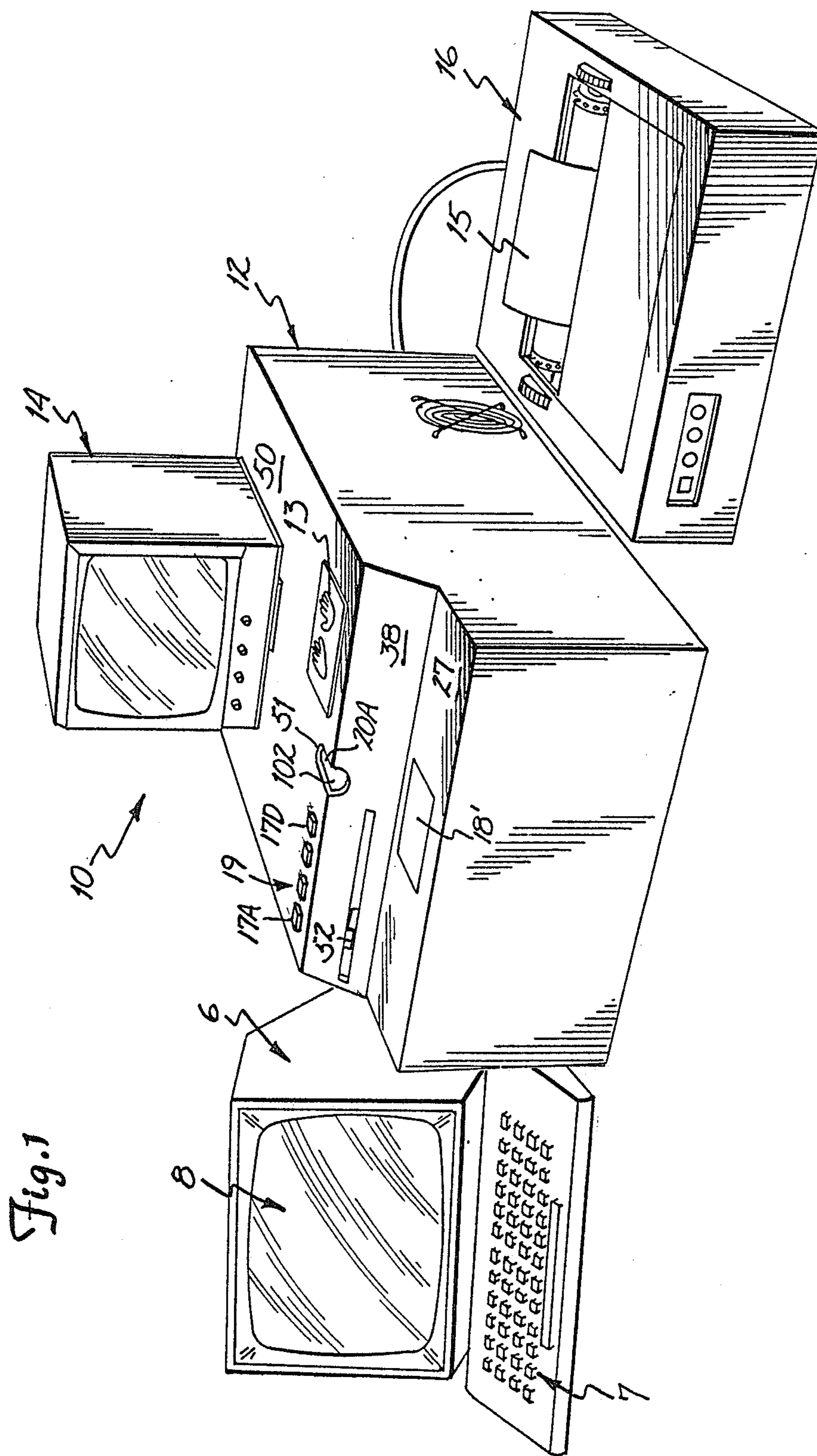
Primary Examiner—Leo H. Boudreau
Assistant Examiner—Donald J. Daley
Attorney, Agent, or Firm—Kinney & Lange

[57] **ABSTRACT**

Methods for operating a programmable digital computer to enhance images of fingerprints represented by an array of pixel values. Methods for noise averaging, illumination equalizing, directional filtering, unhairing, curvature correcting, and scale correcting a fingerprint image are disclosed.

7 Claims, 28 Drawing Sheets





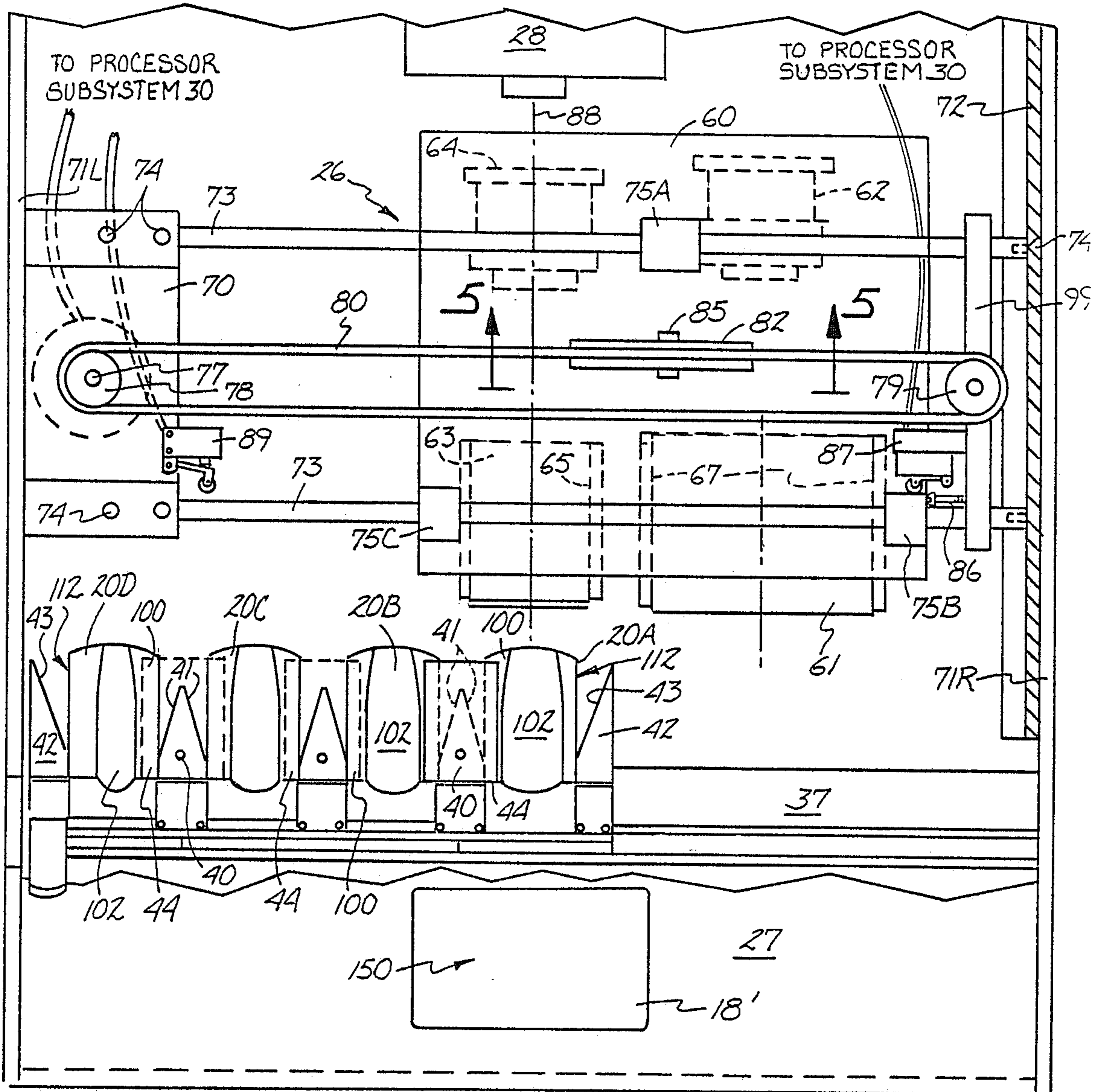


Fig. 2

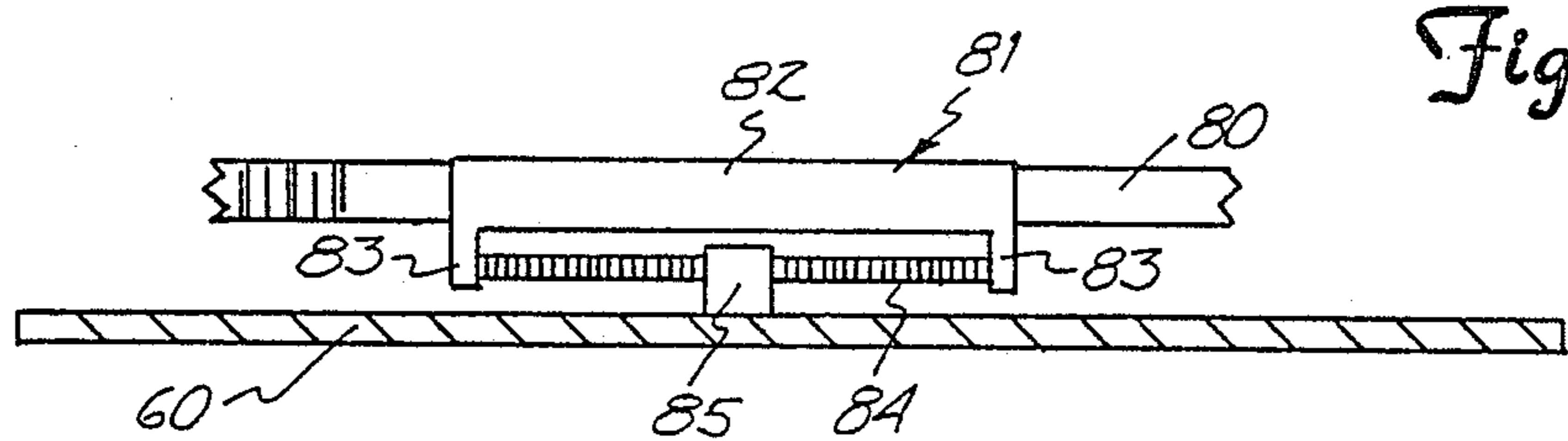


Fig. 5

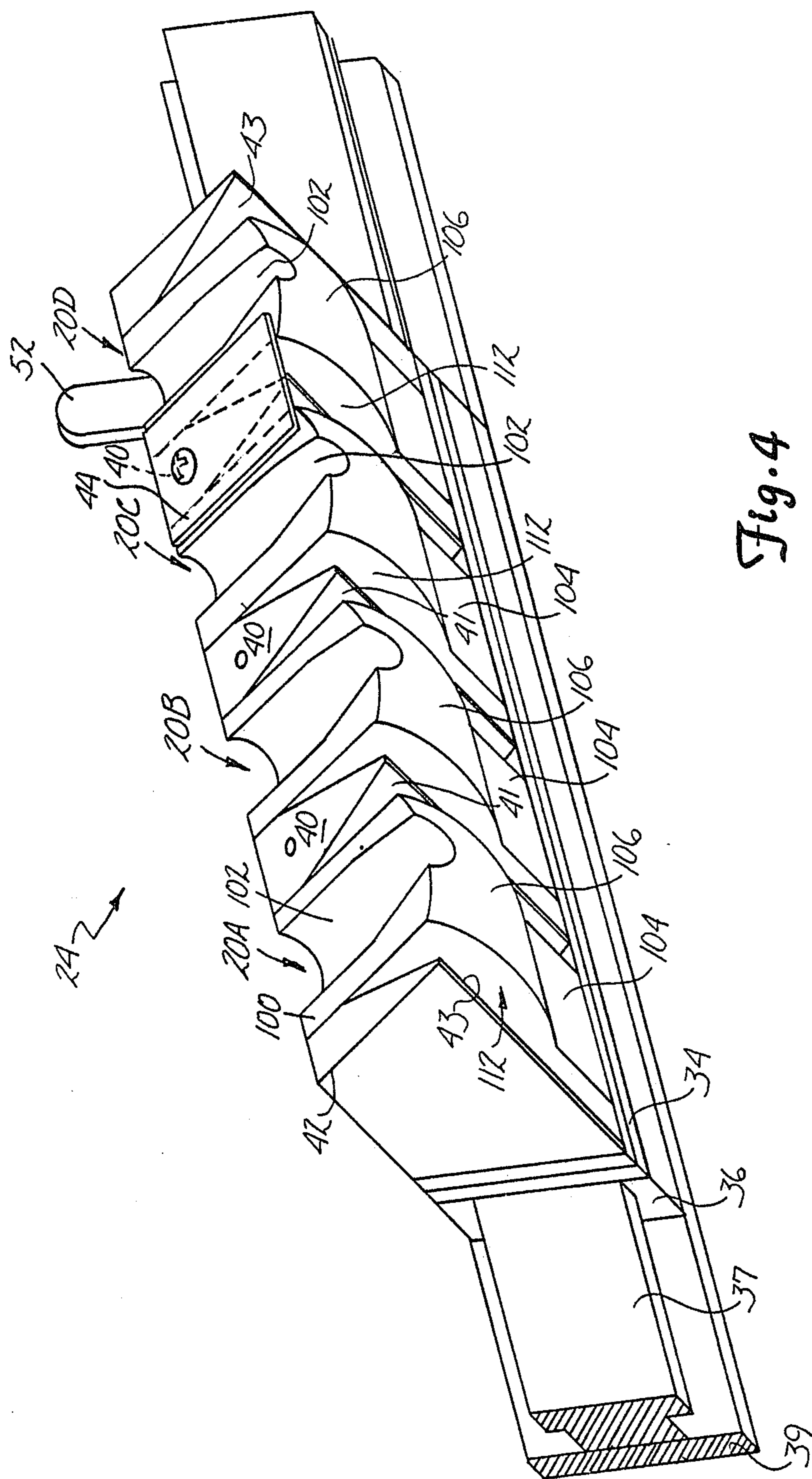
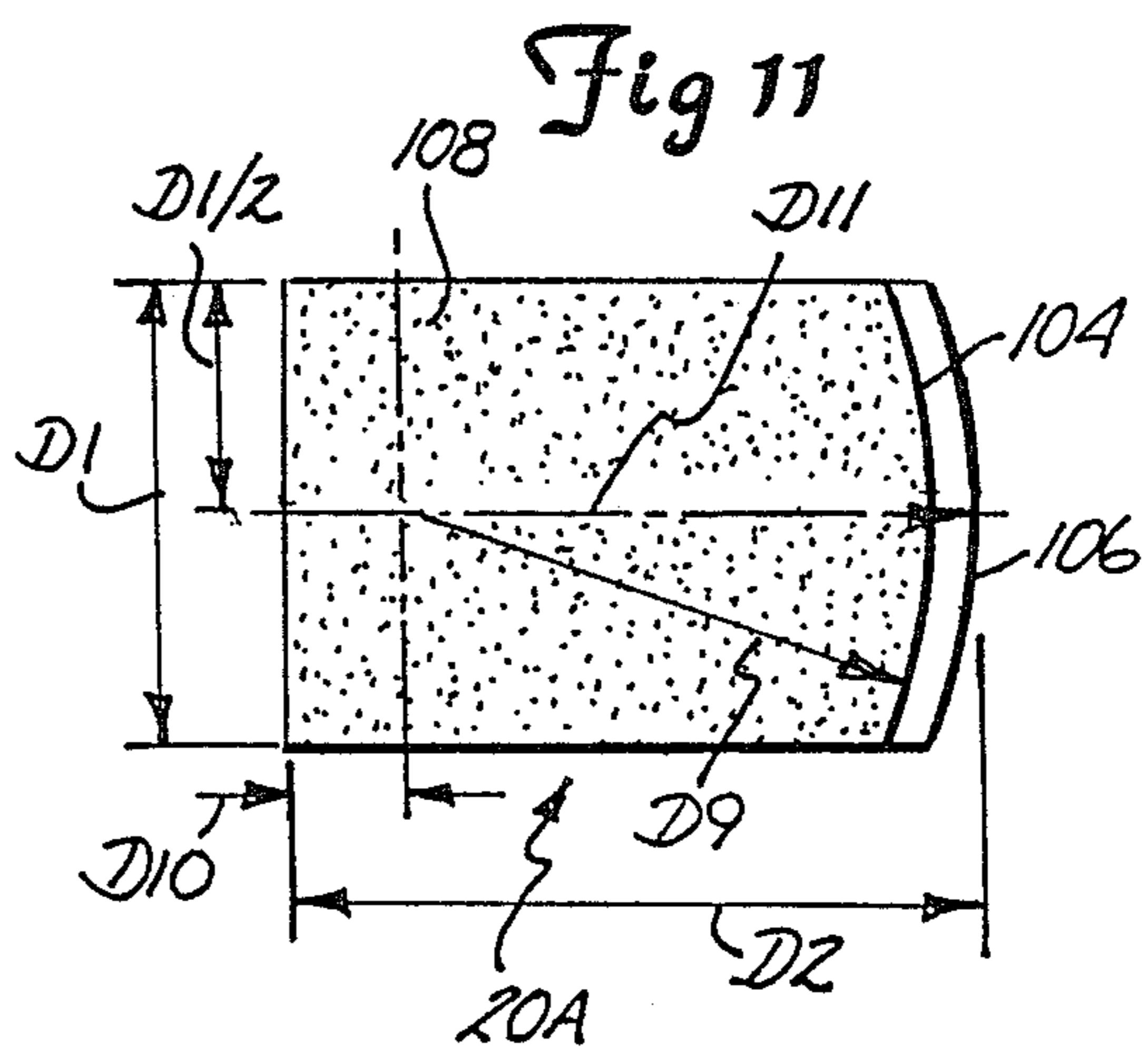
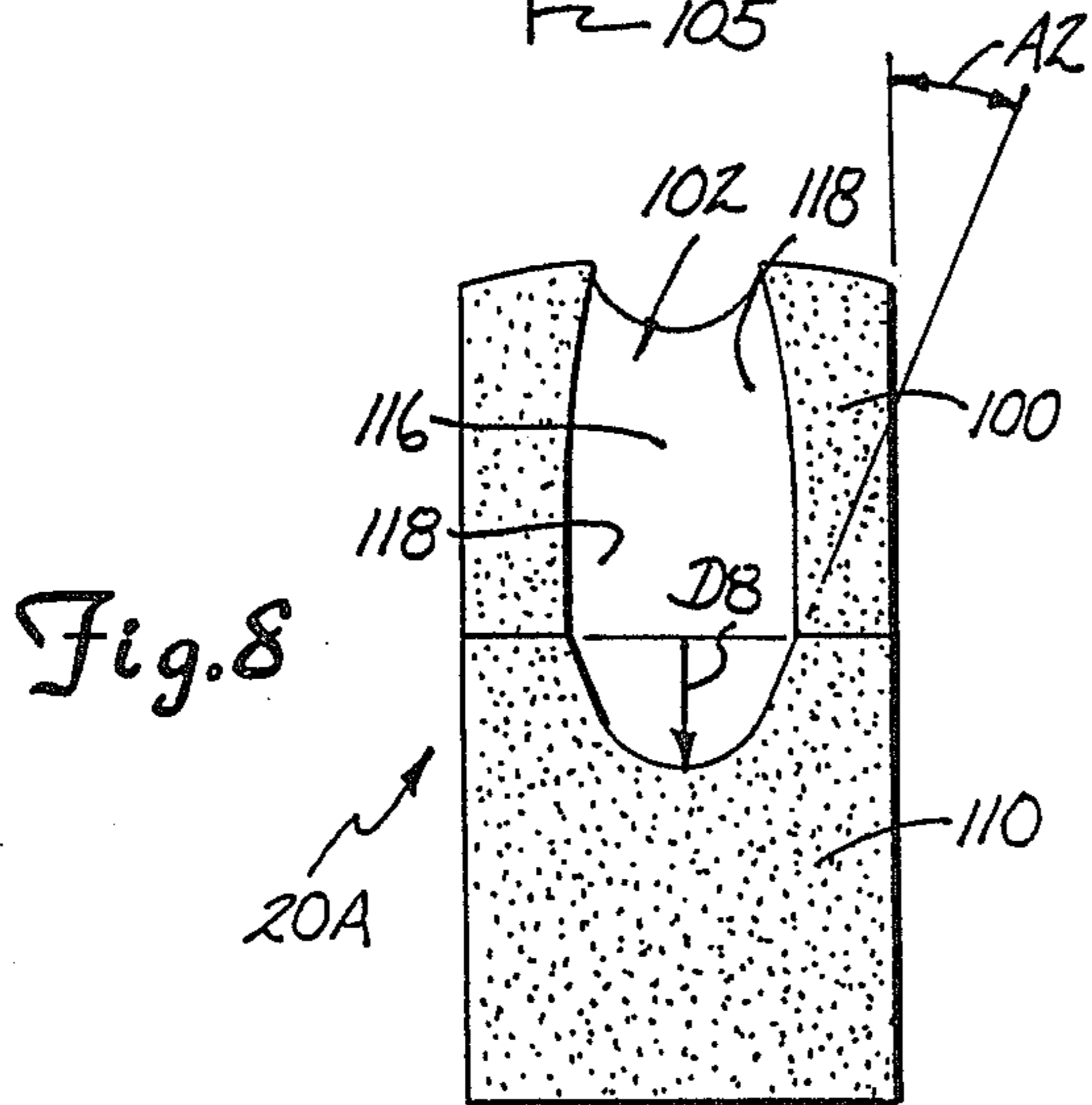
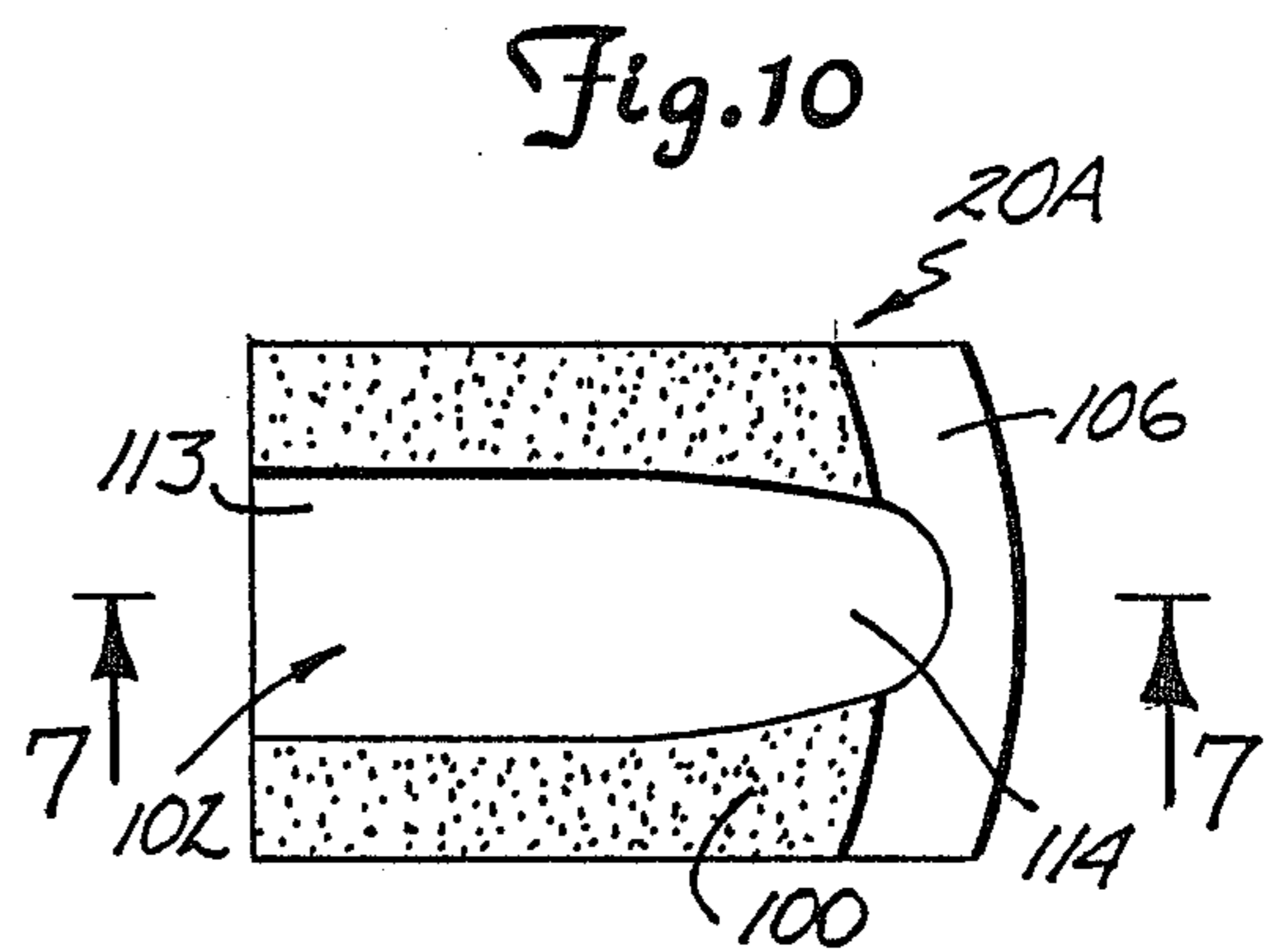
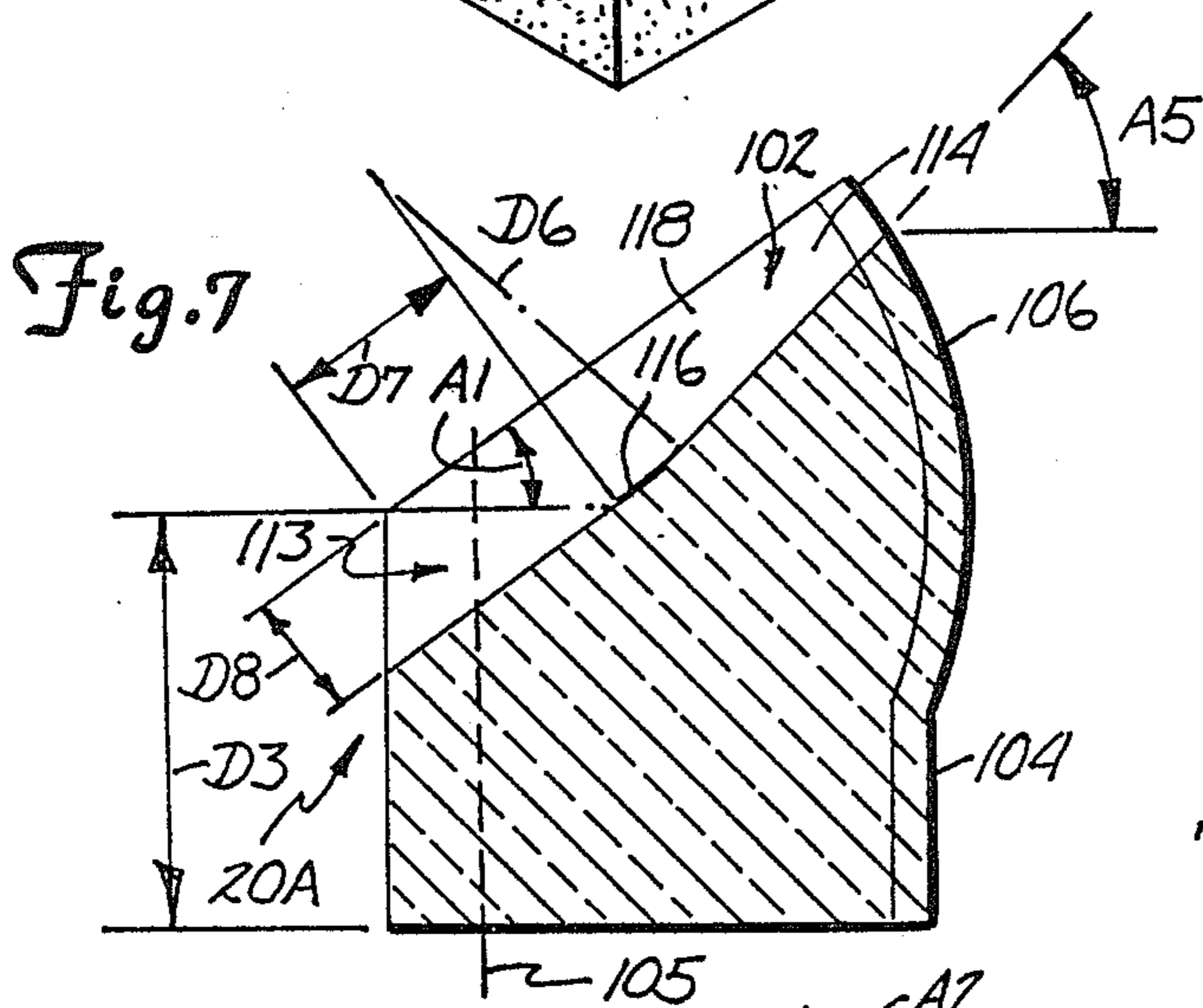
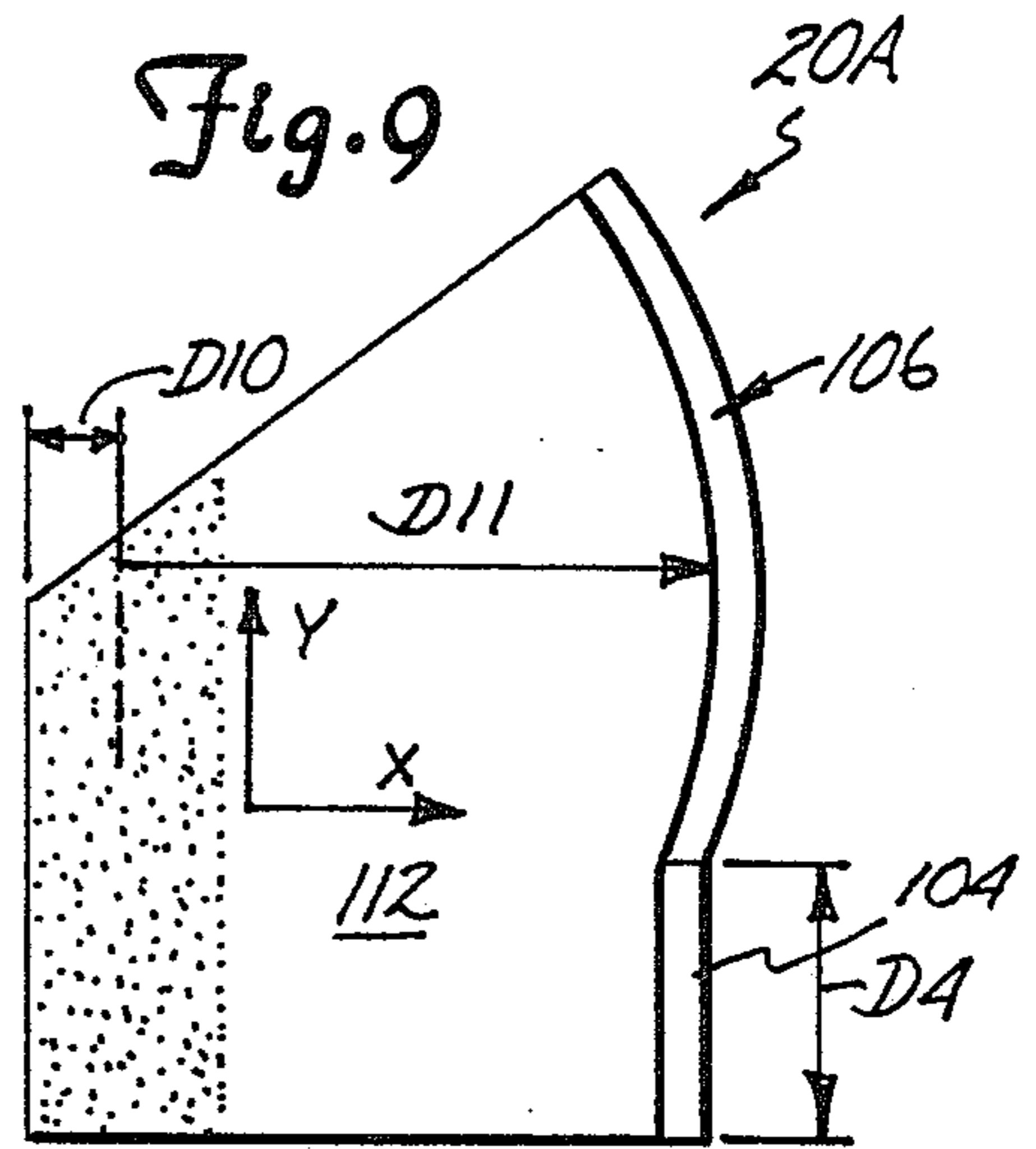
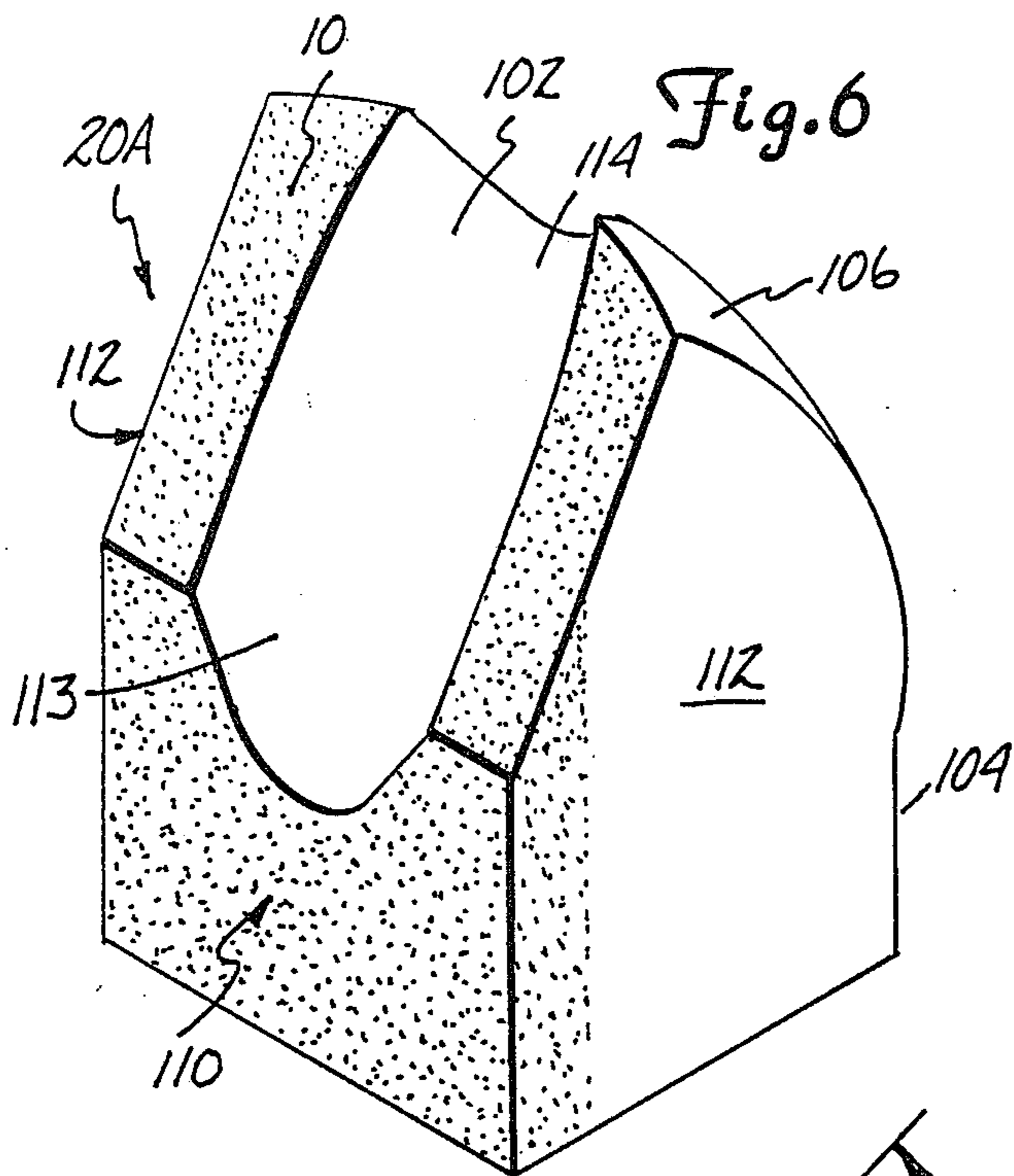


Fig. 4



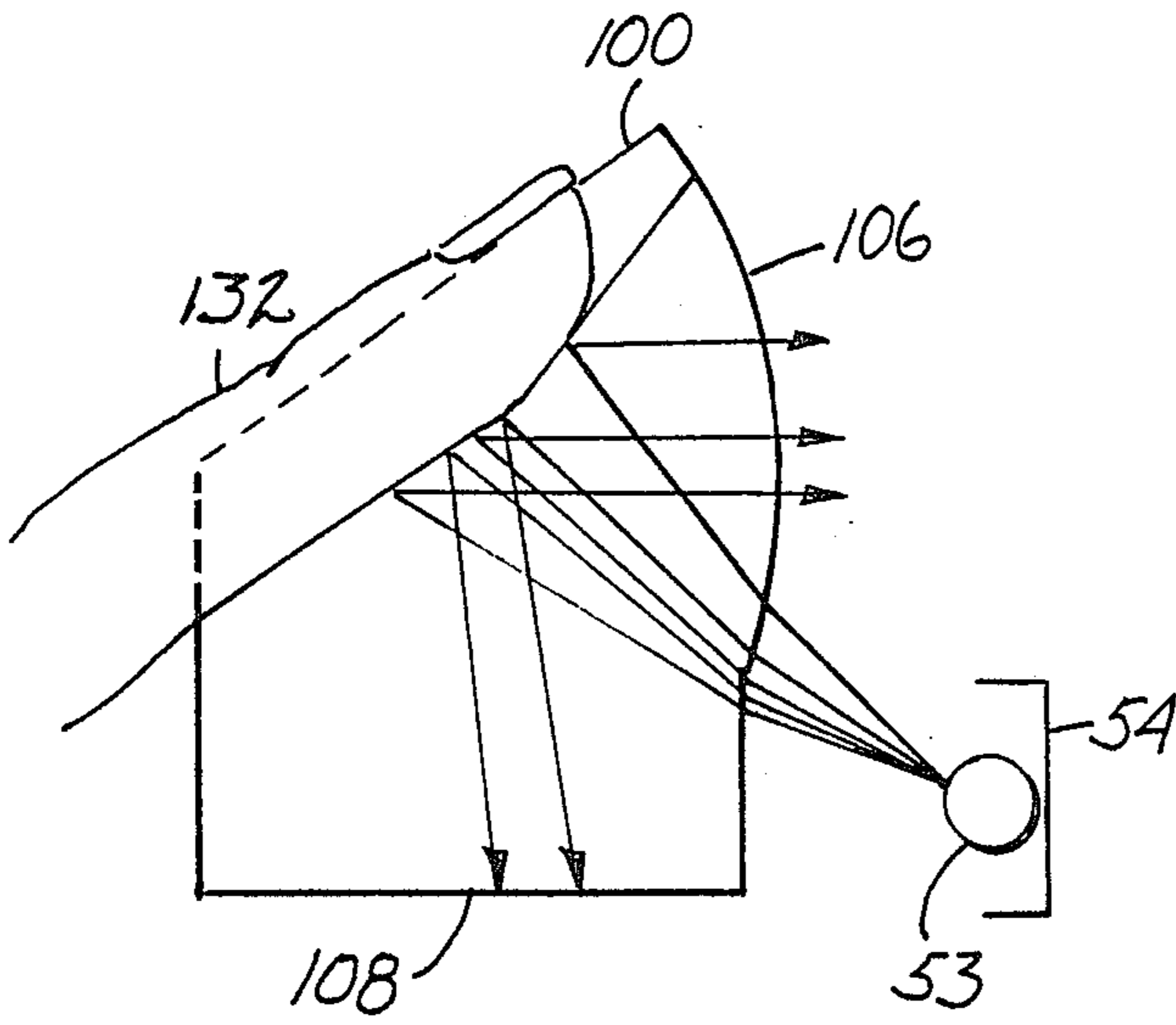


Fig. 13

Fig. 12

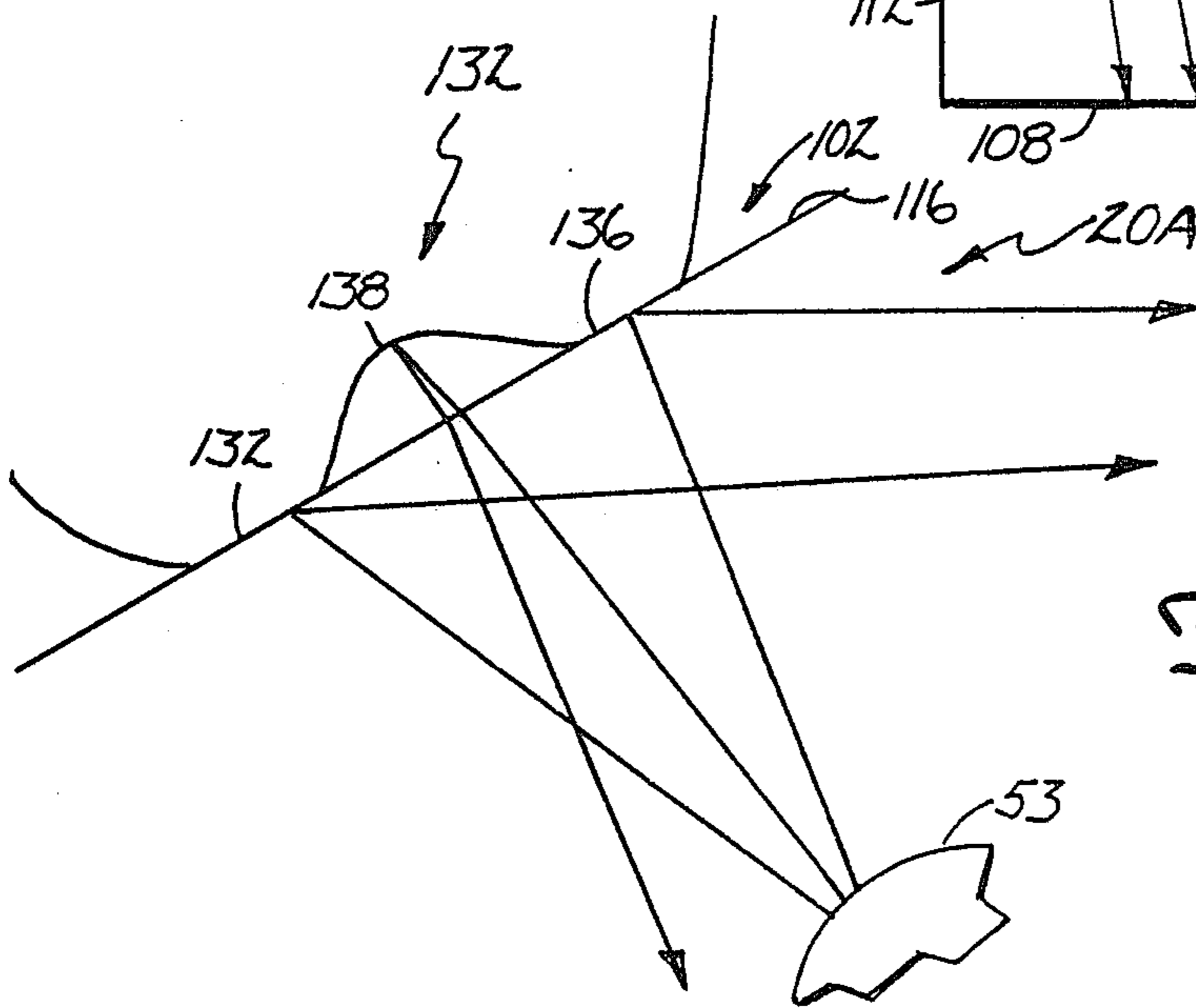
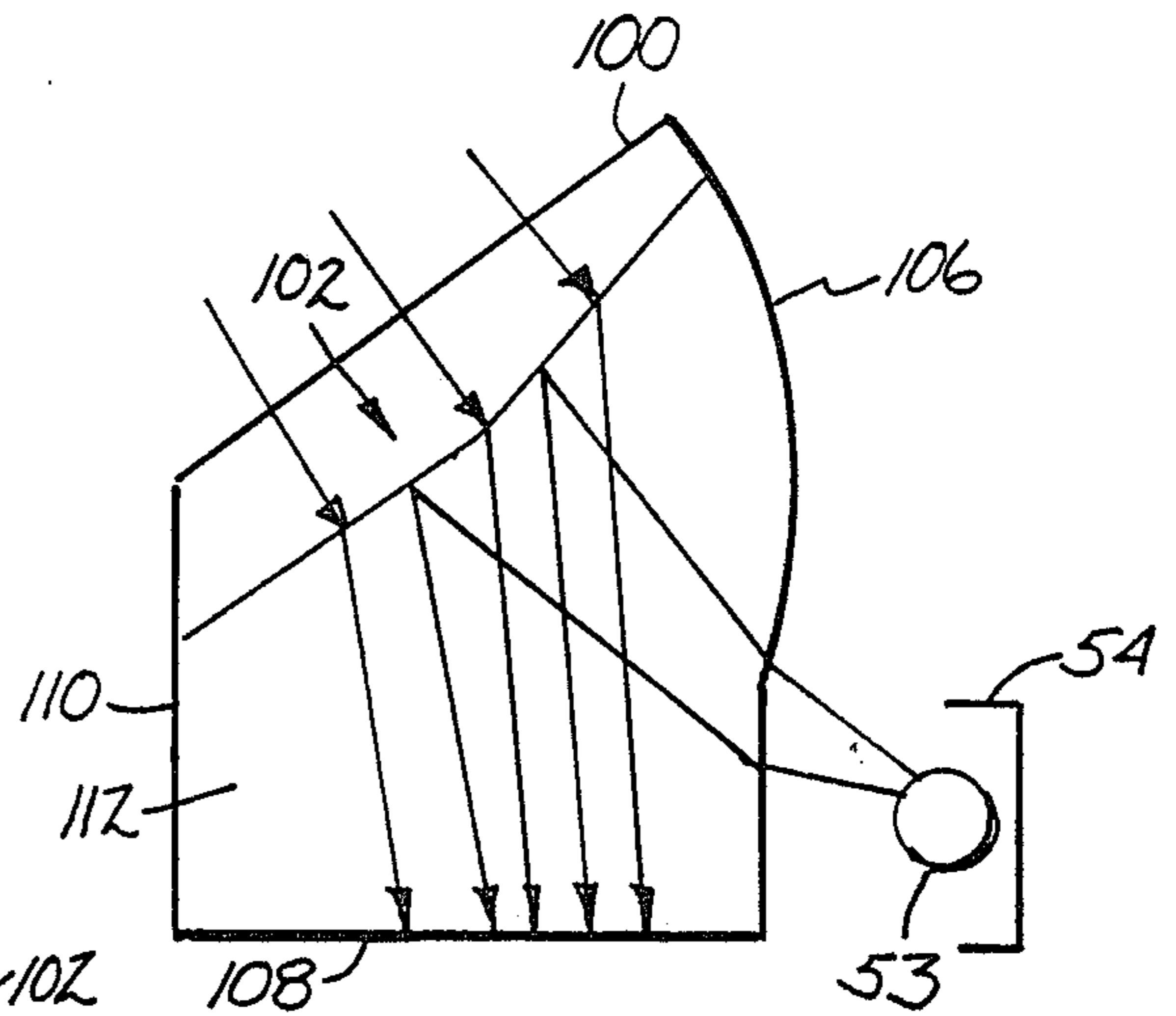


Fig. 14

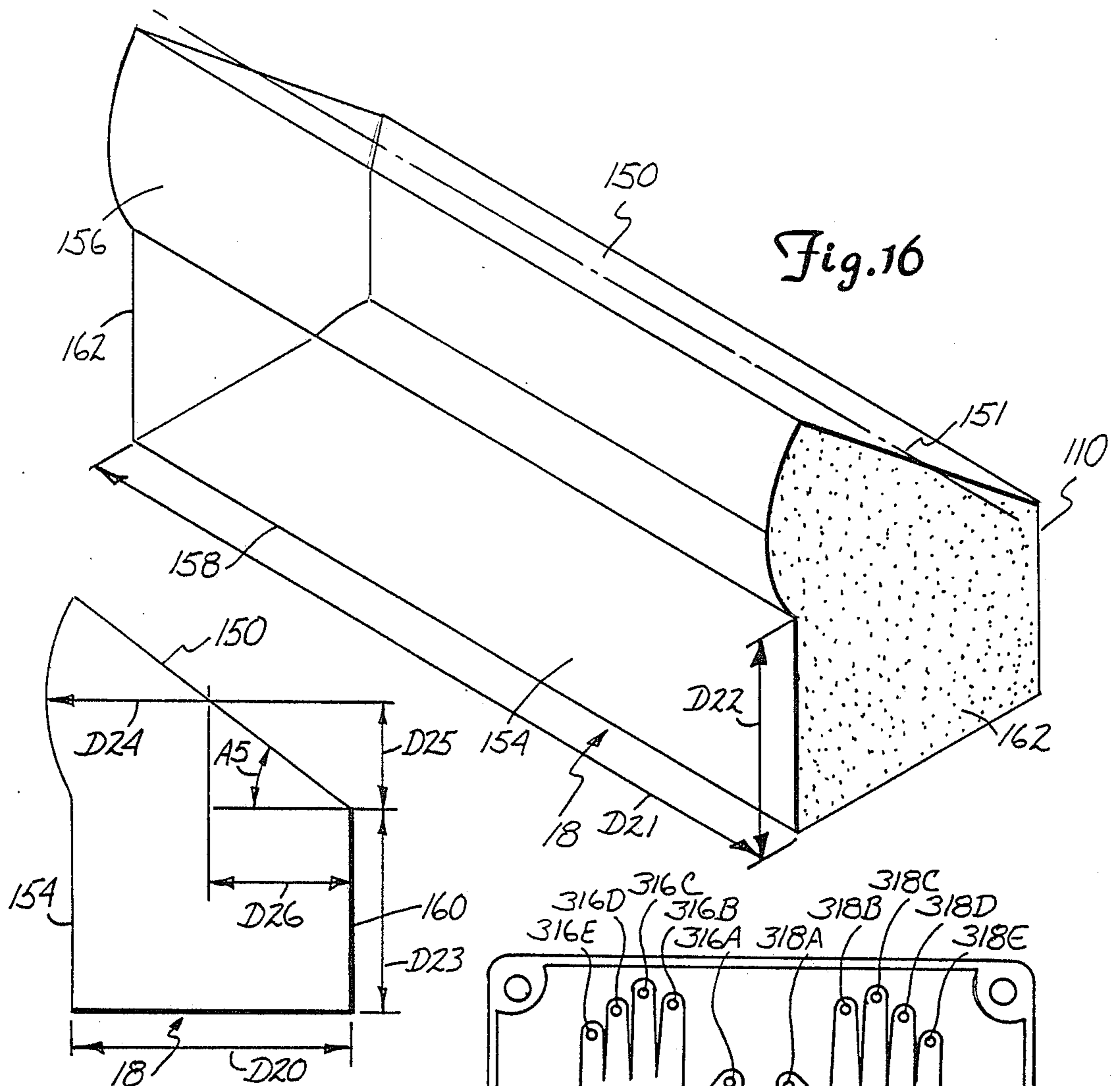


Fig. 16

Fig. 17

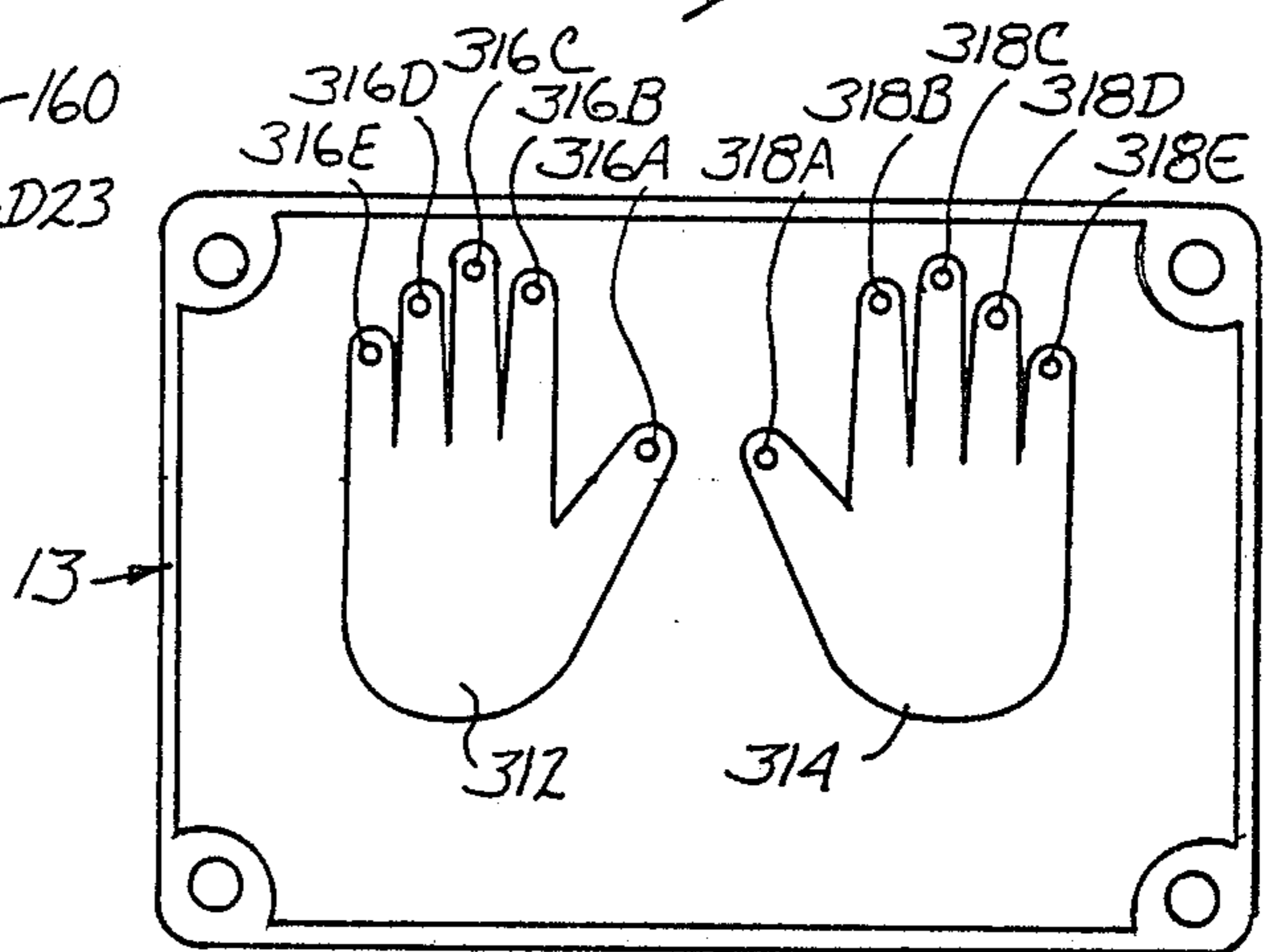


Fig. 43

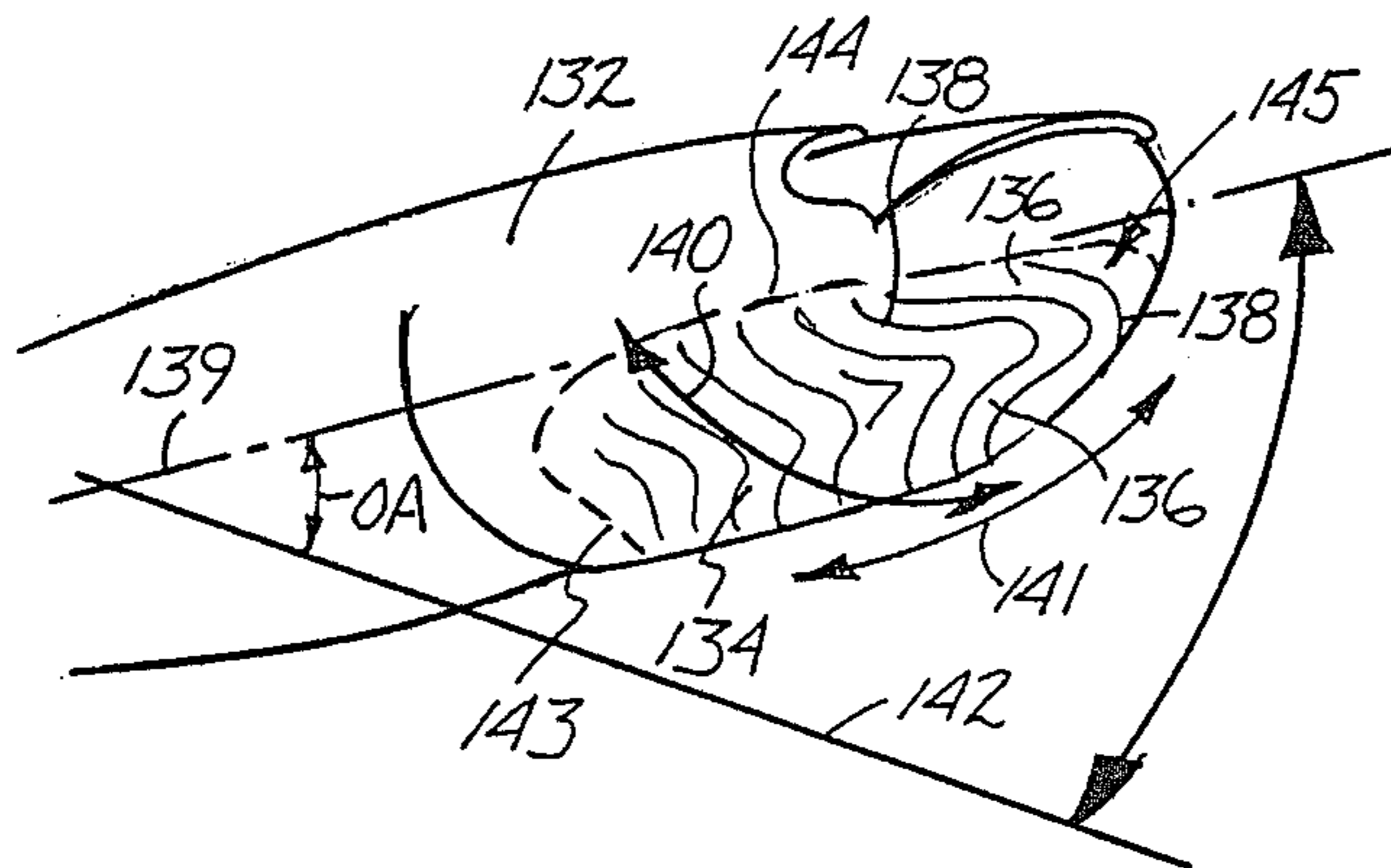
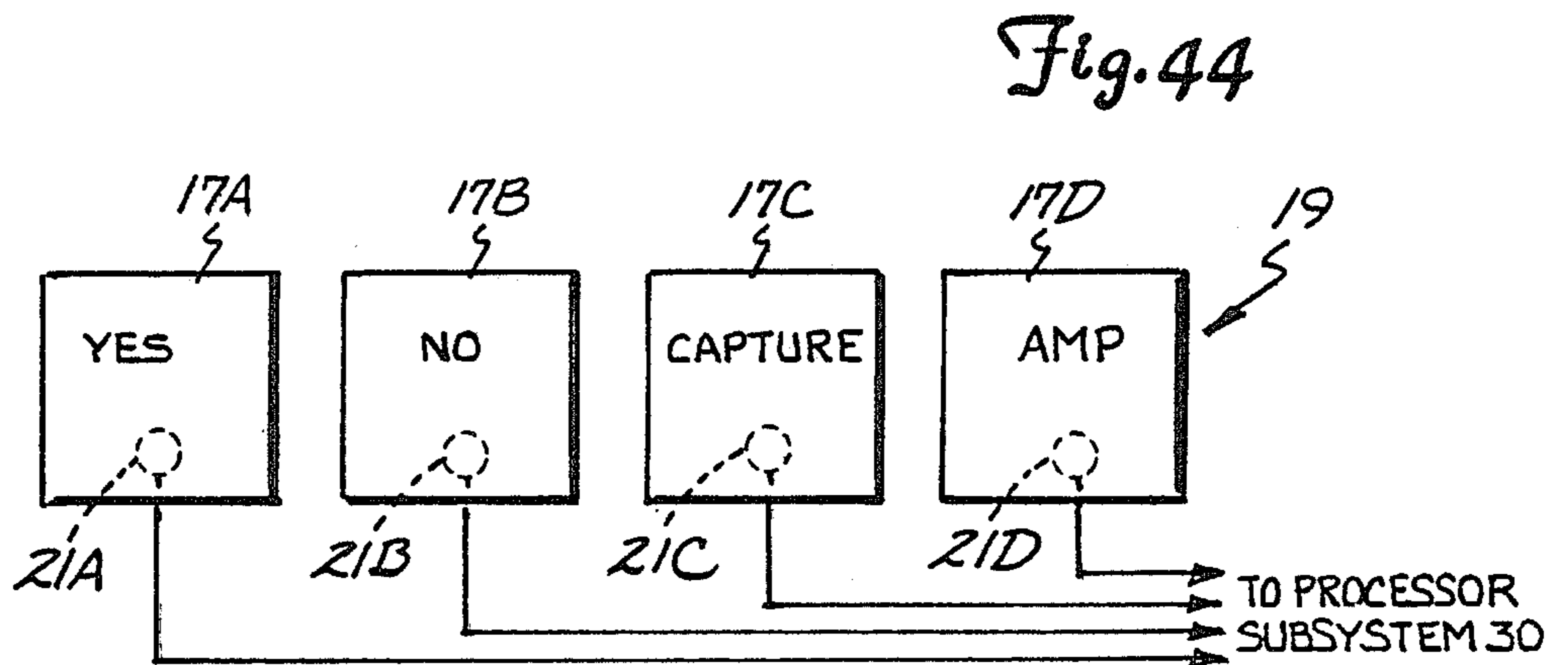
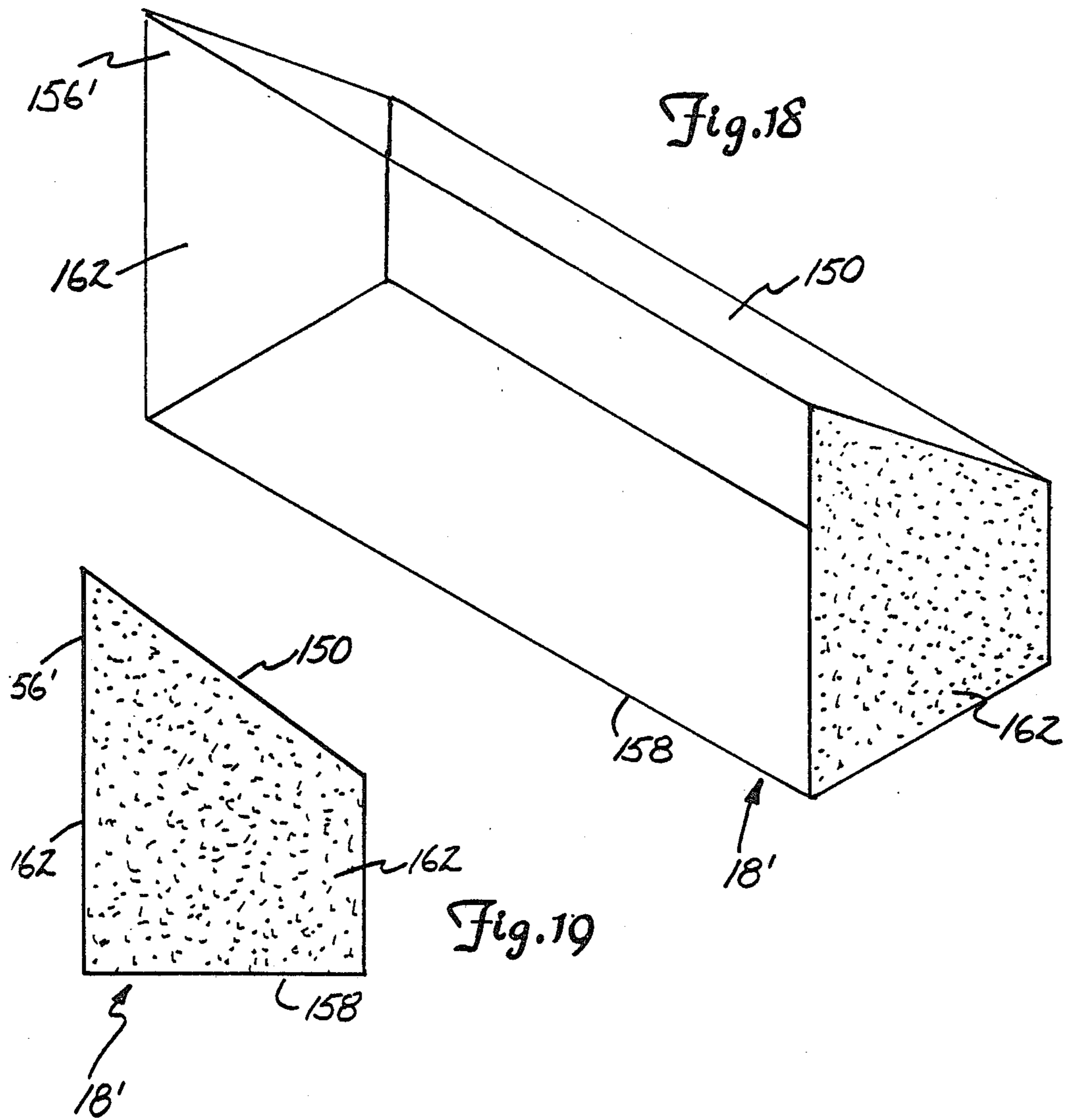


Fig. 15



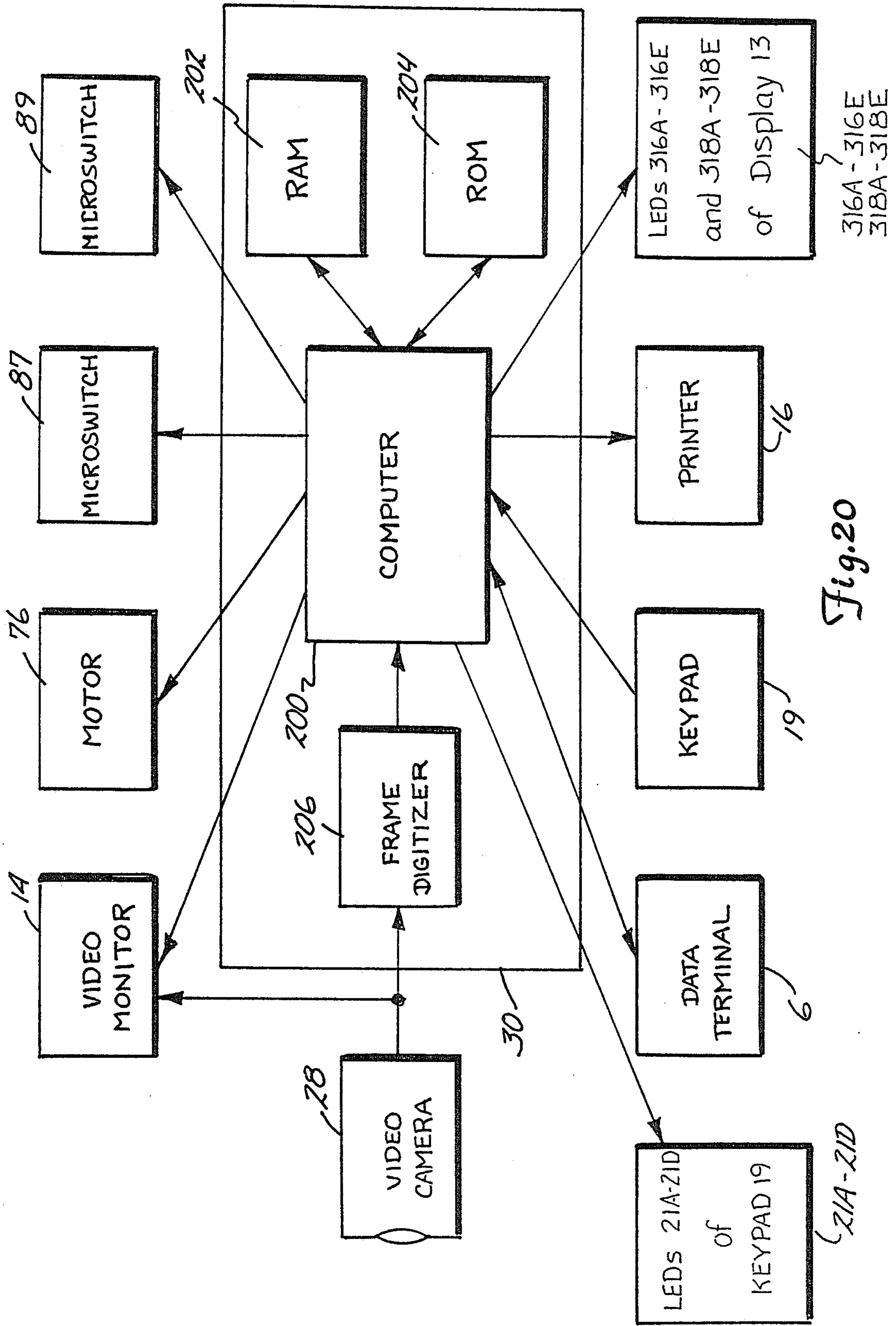
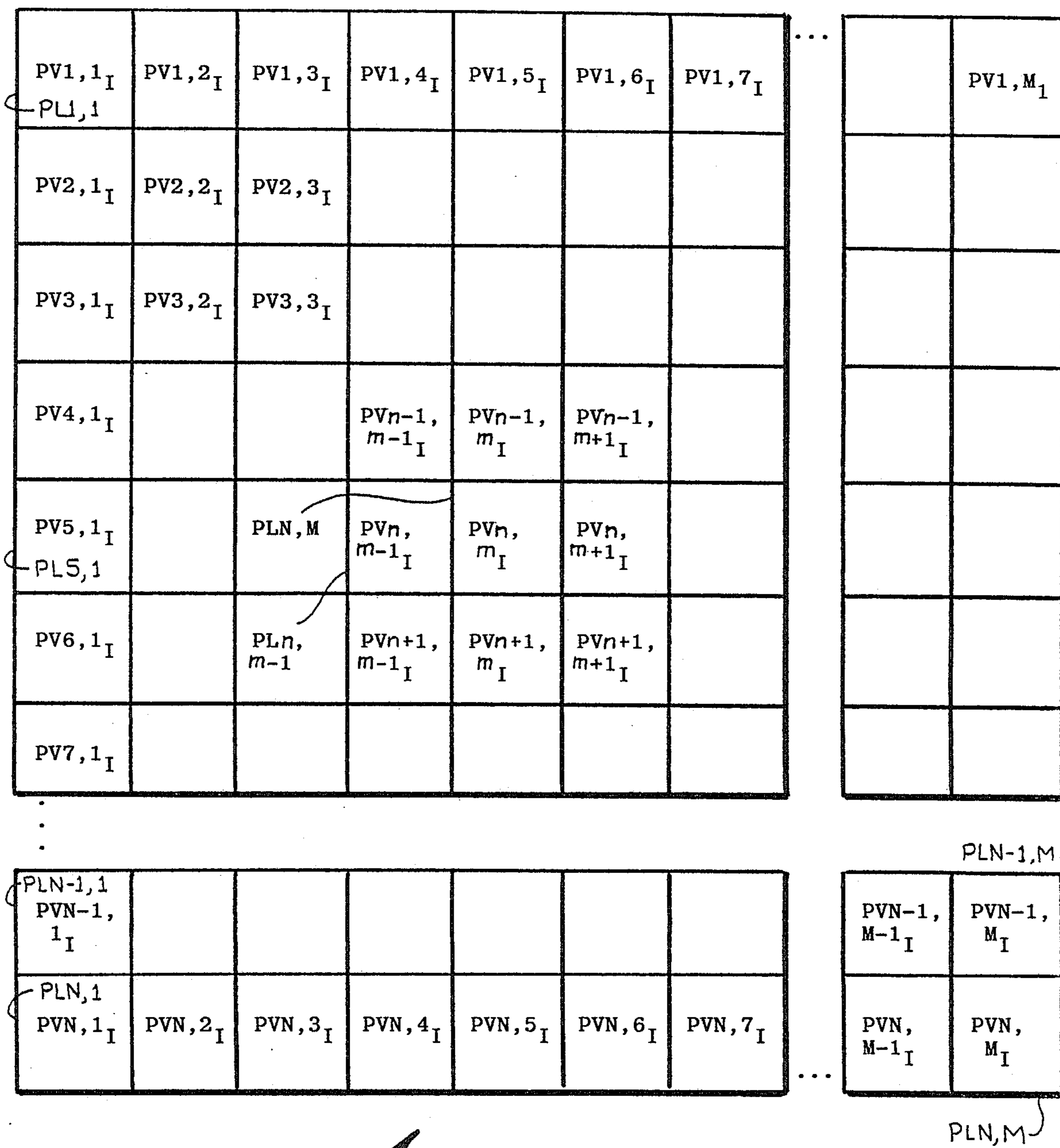
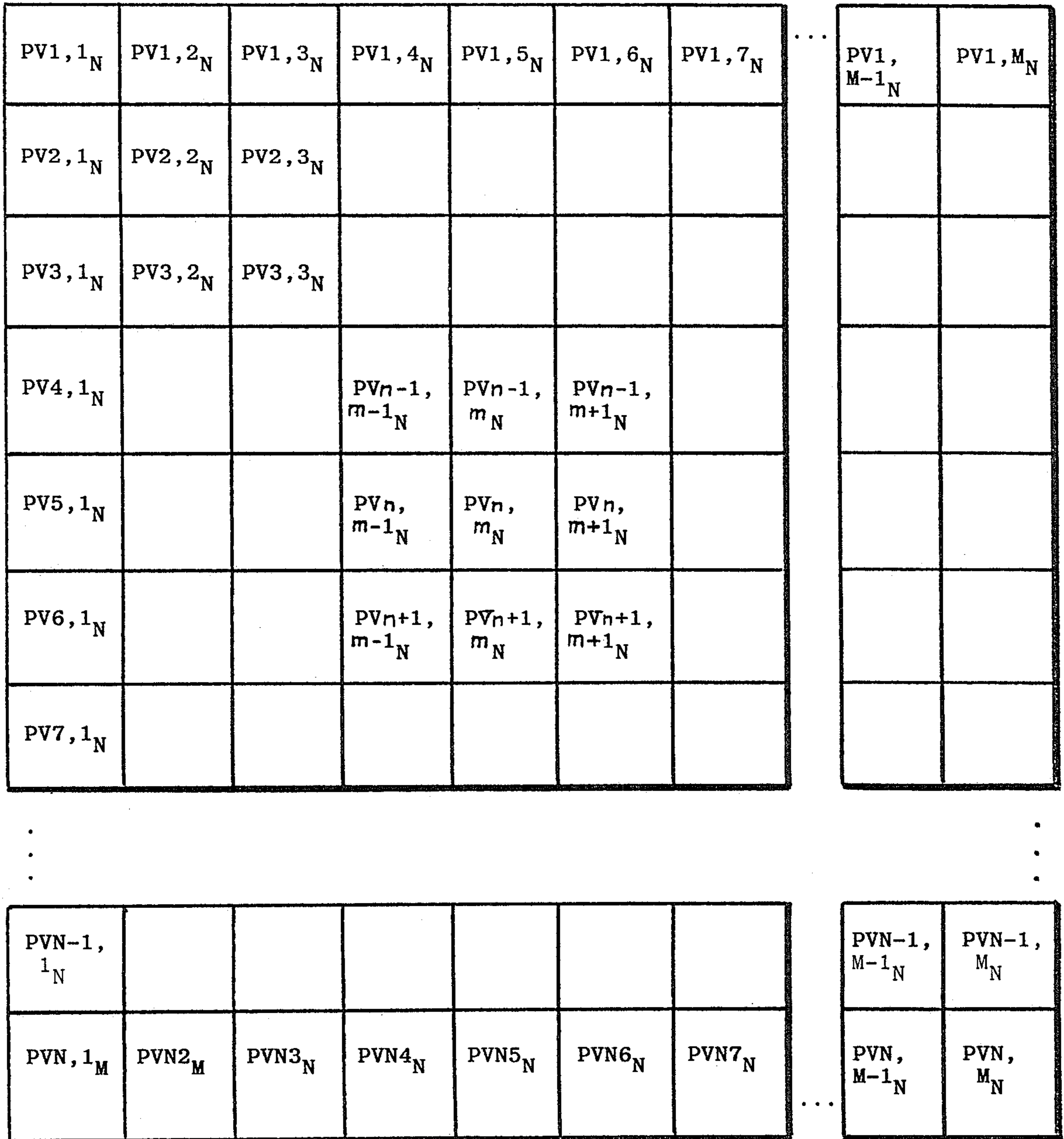


Fig. 20



IA

Fig. 21



NAA ↗

Fig.22

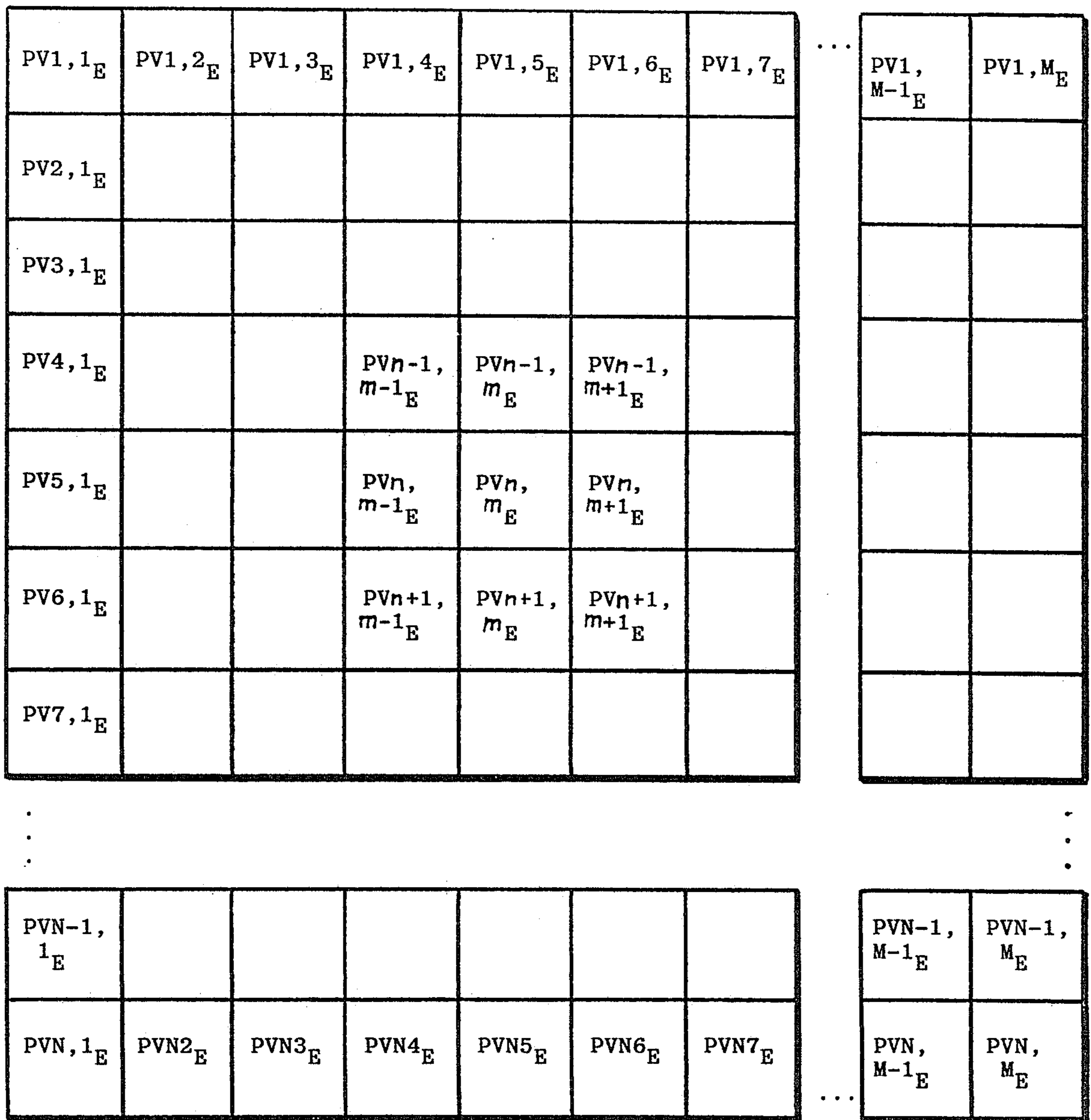
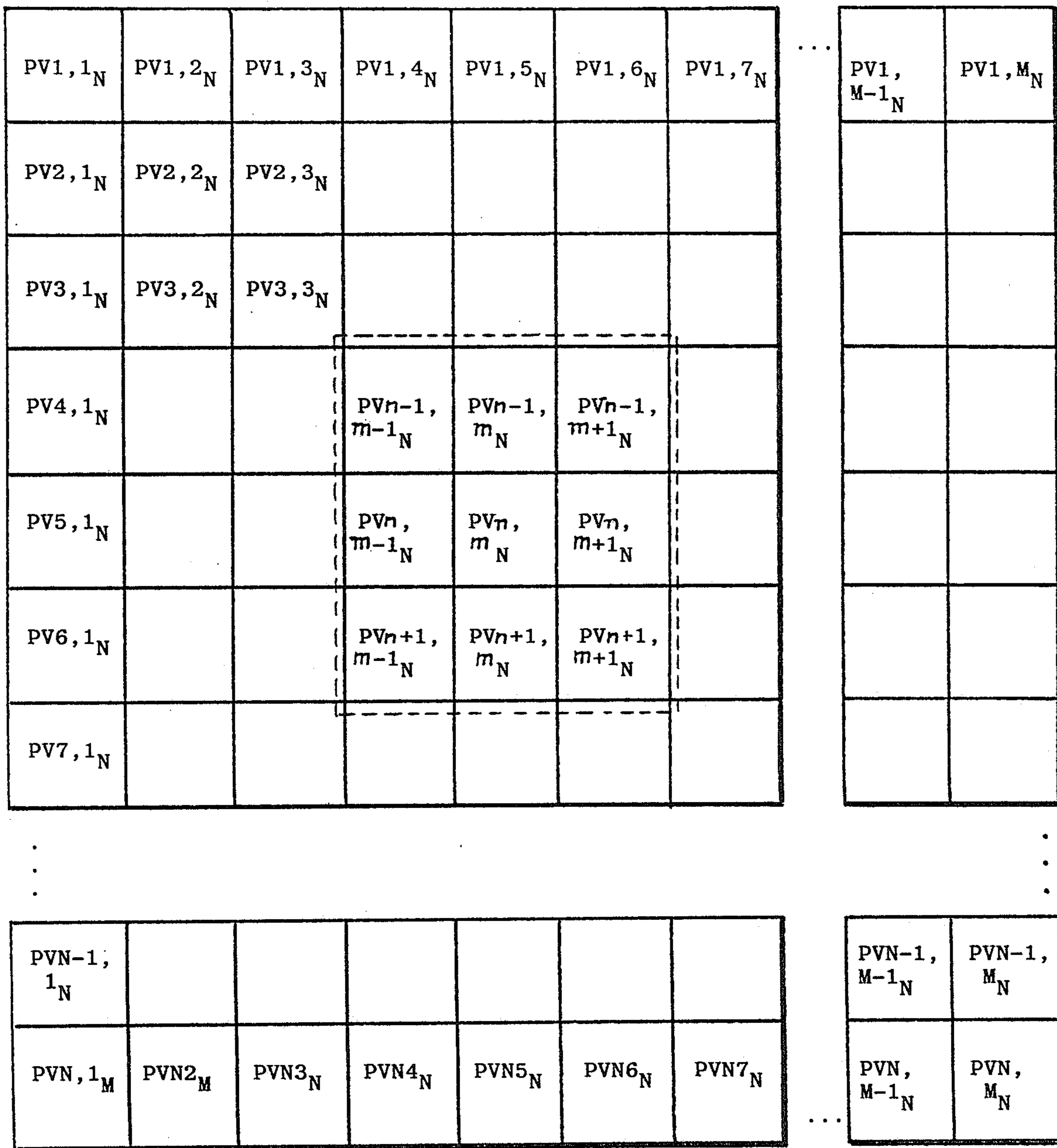
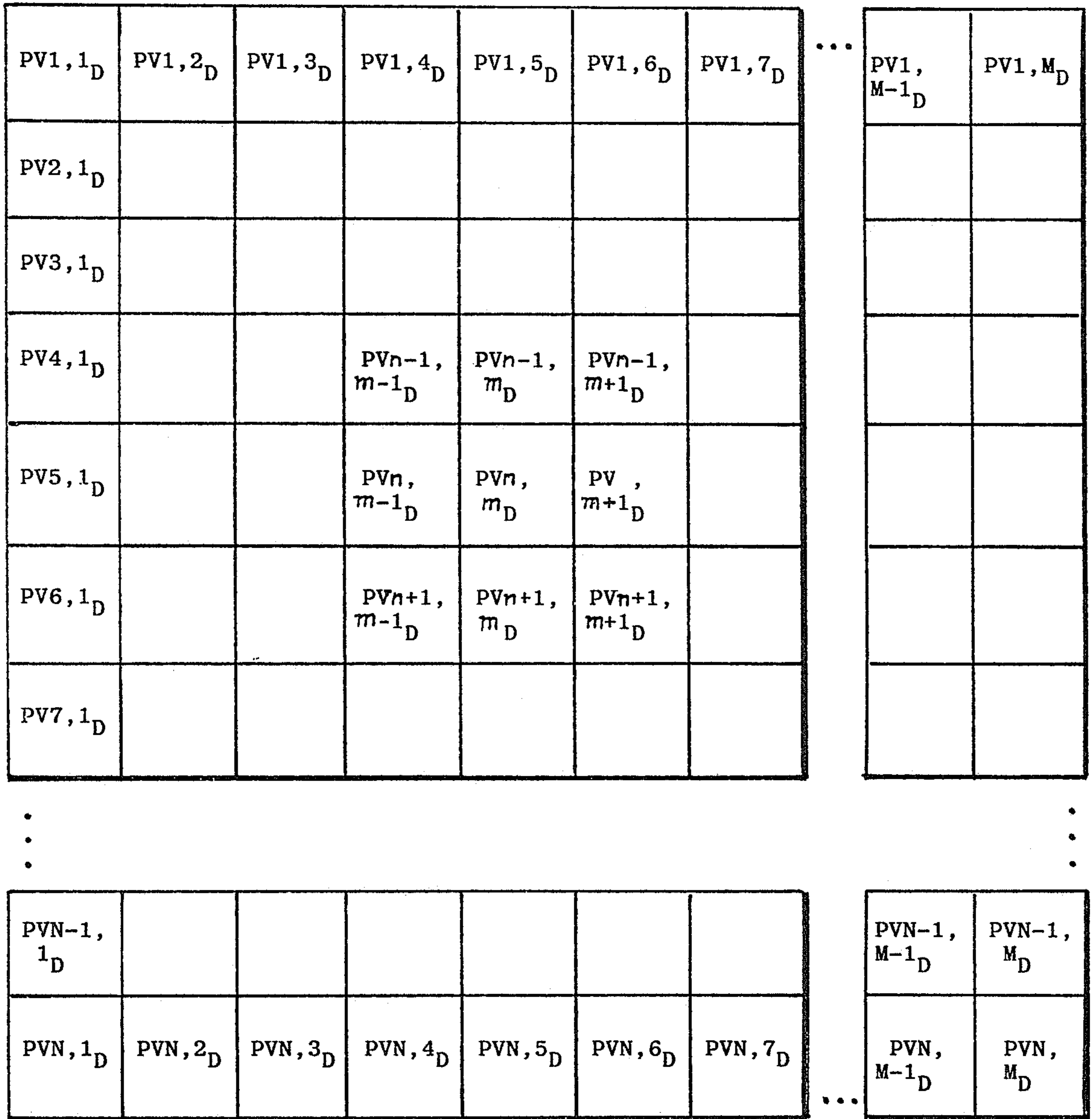


Fig. 23



NAA ↗

Fig. 24



DFA

Fig.25

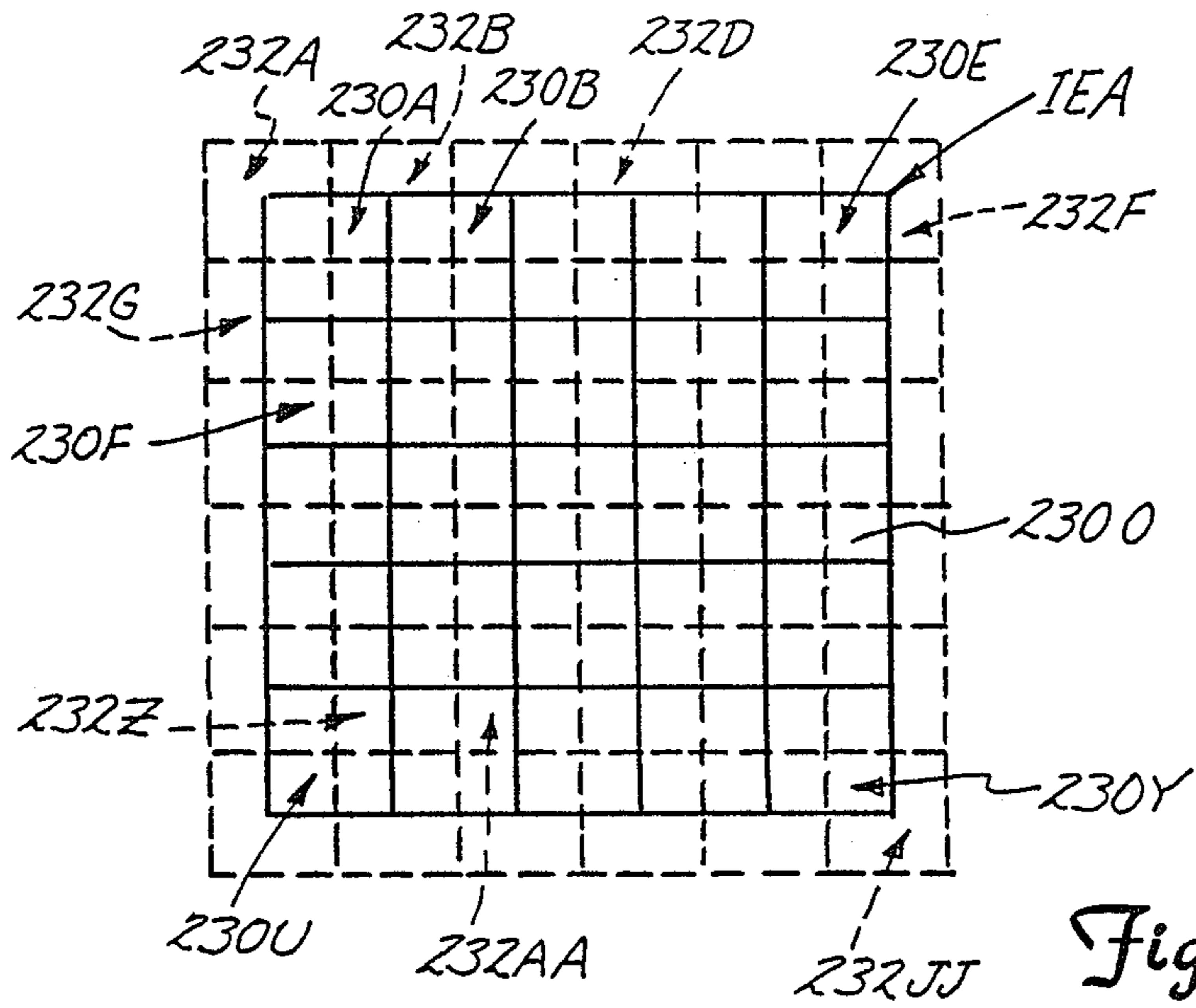


Fig. 26

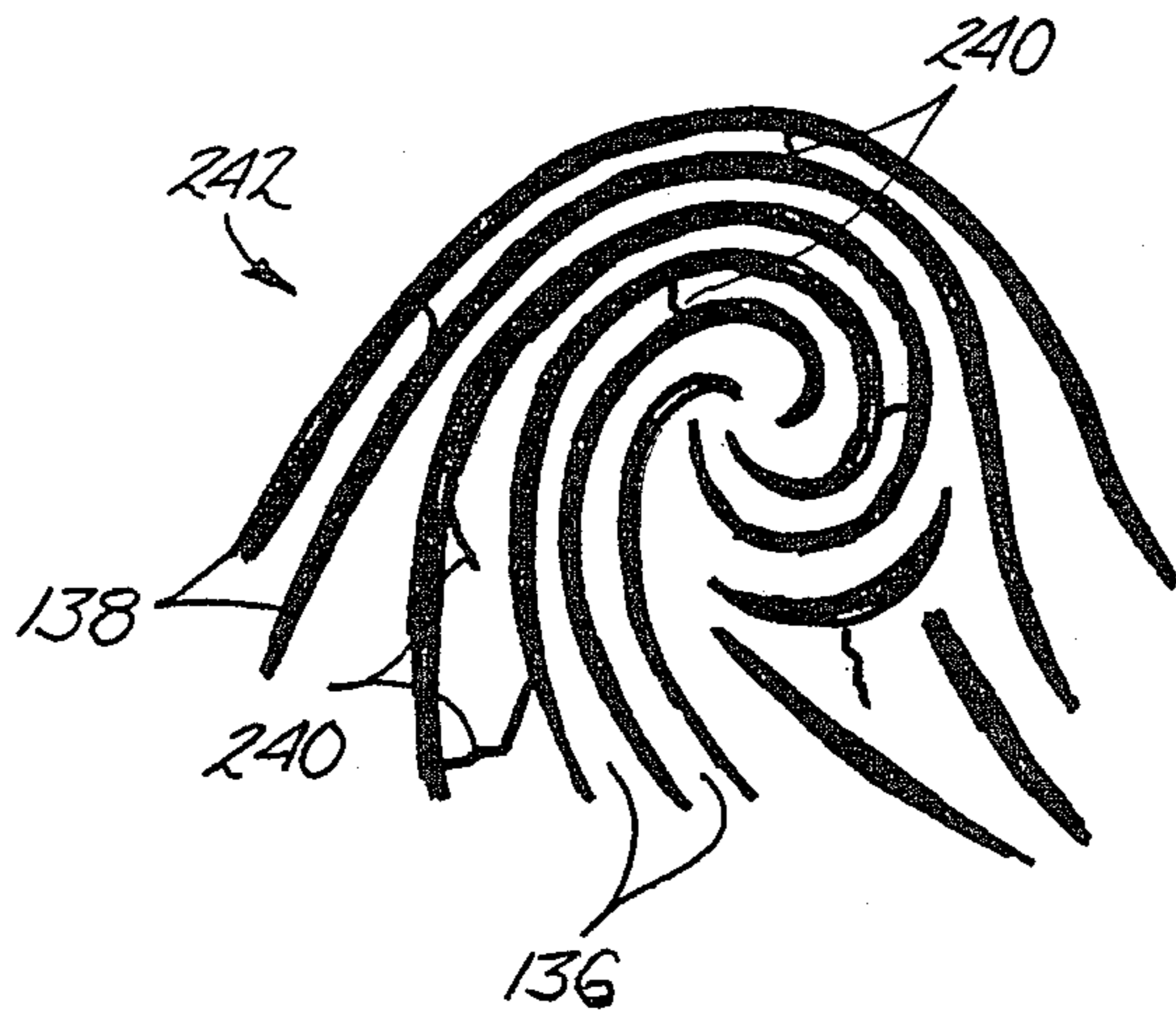
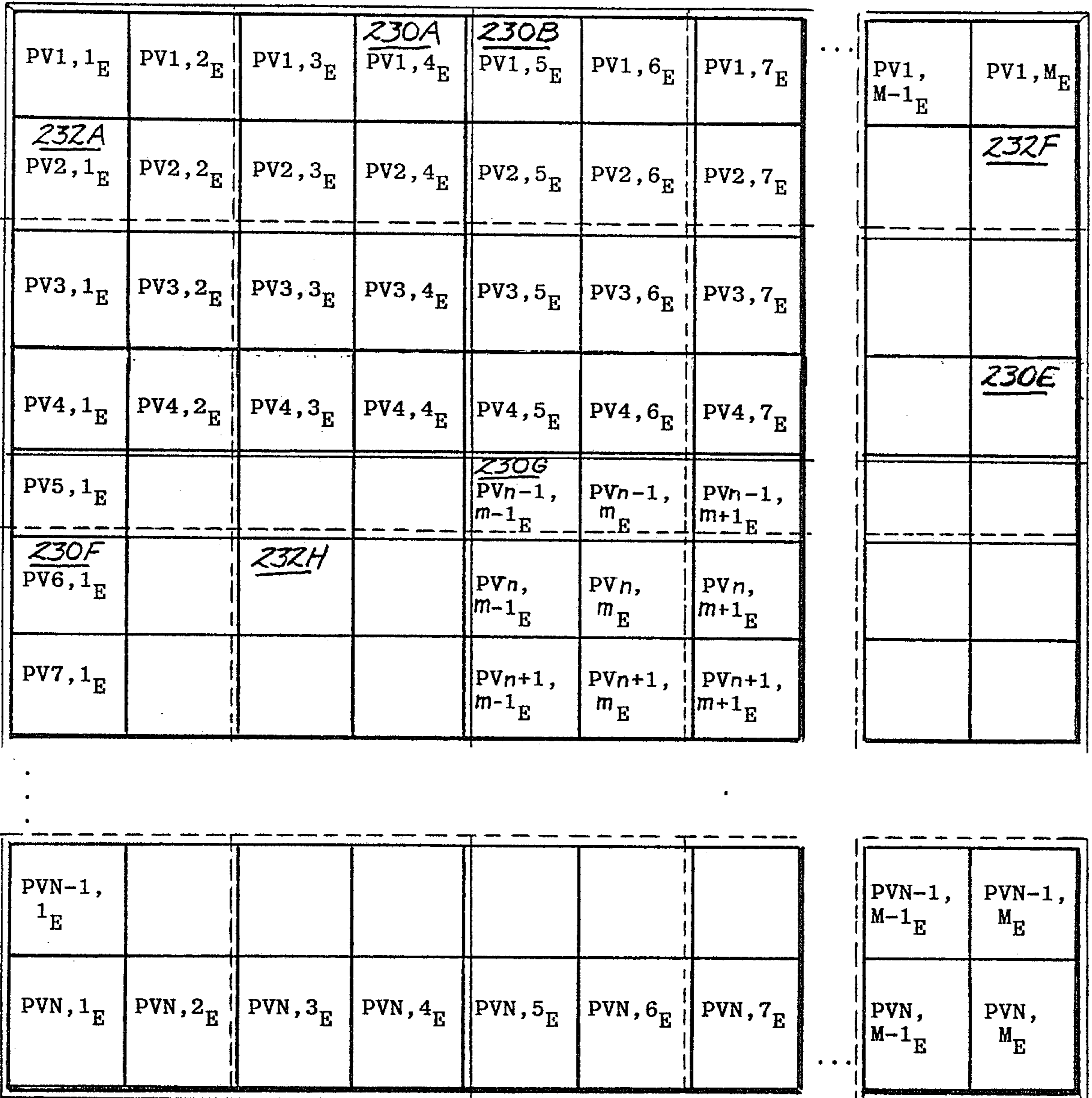
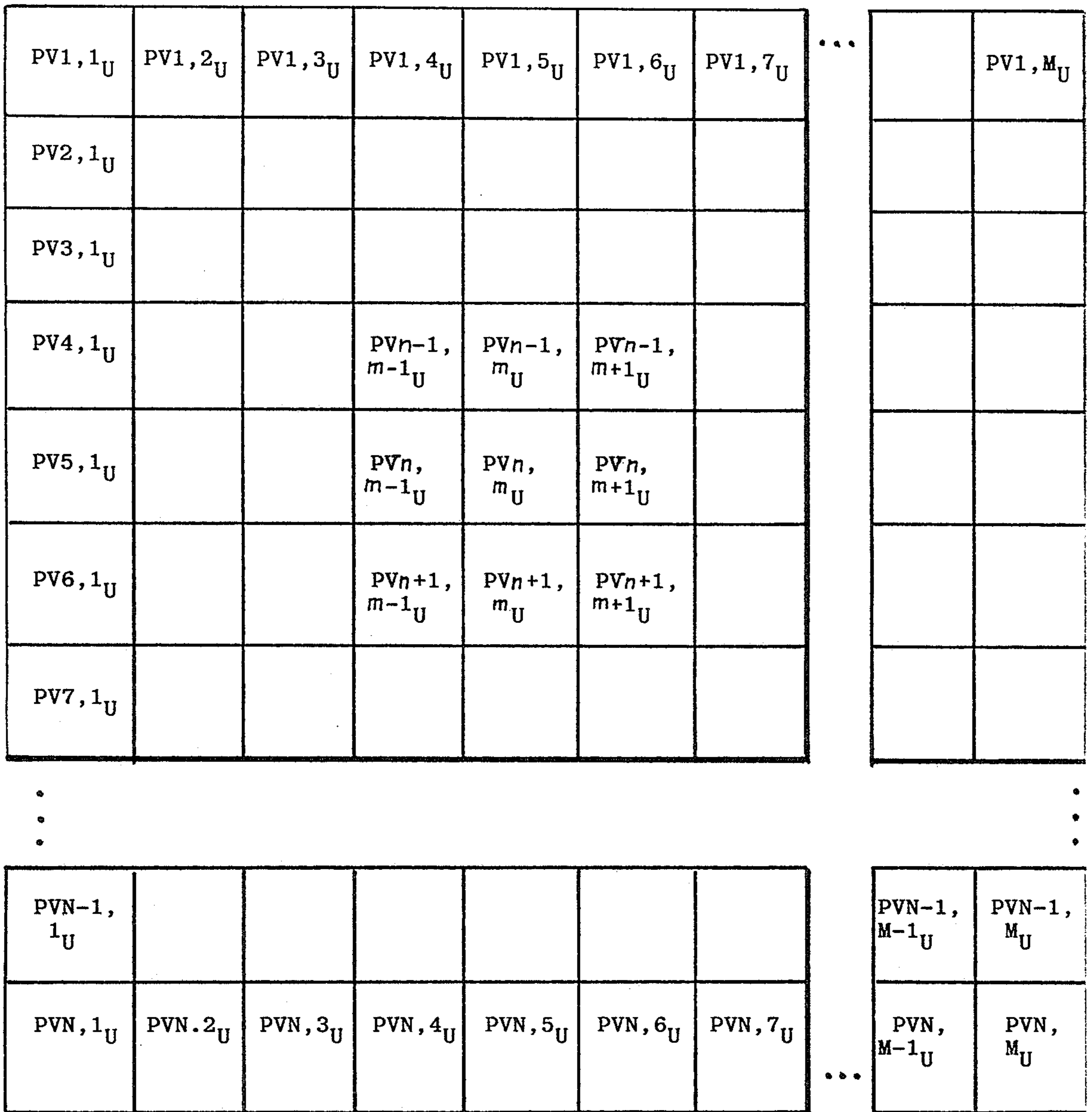


Fig. 28



IEA ↗

Fig. 27



UA ↗

Fig.29

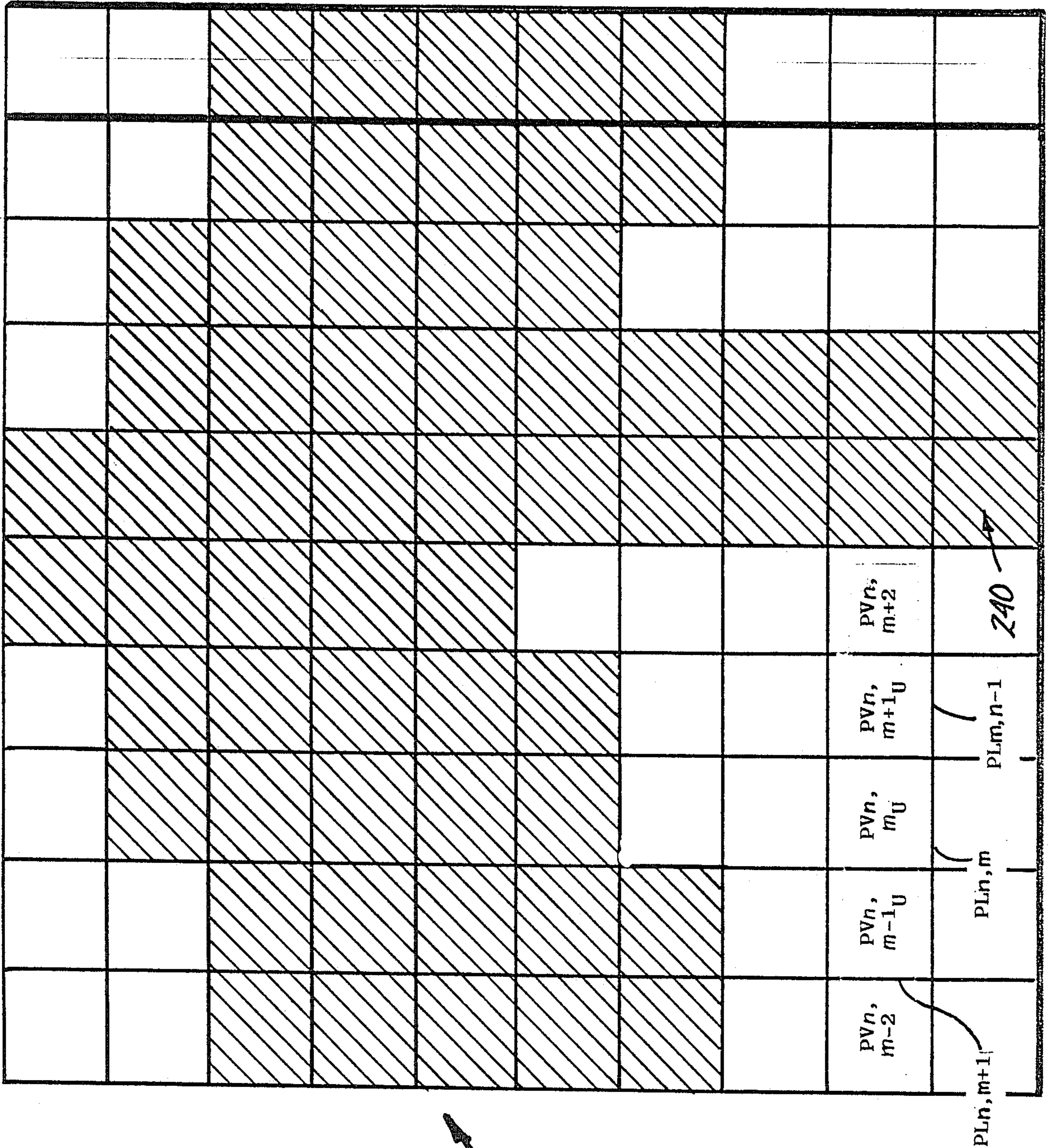
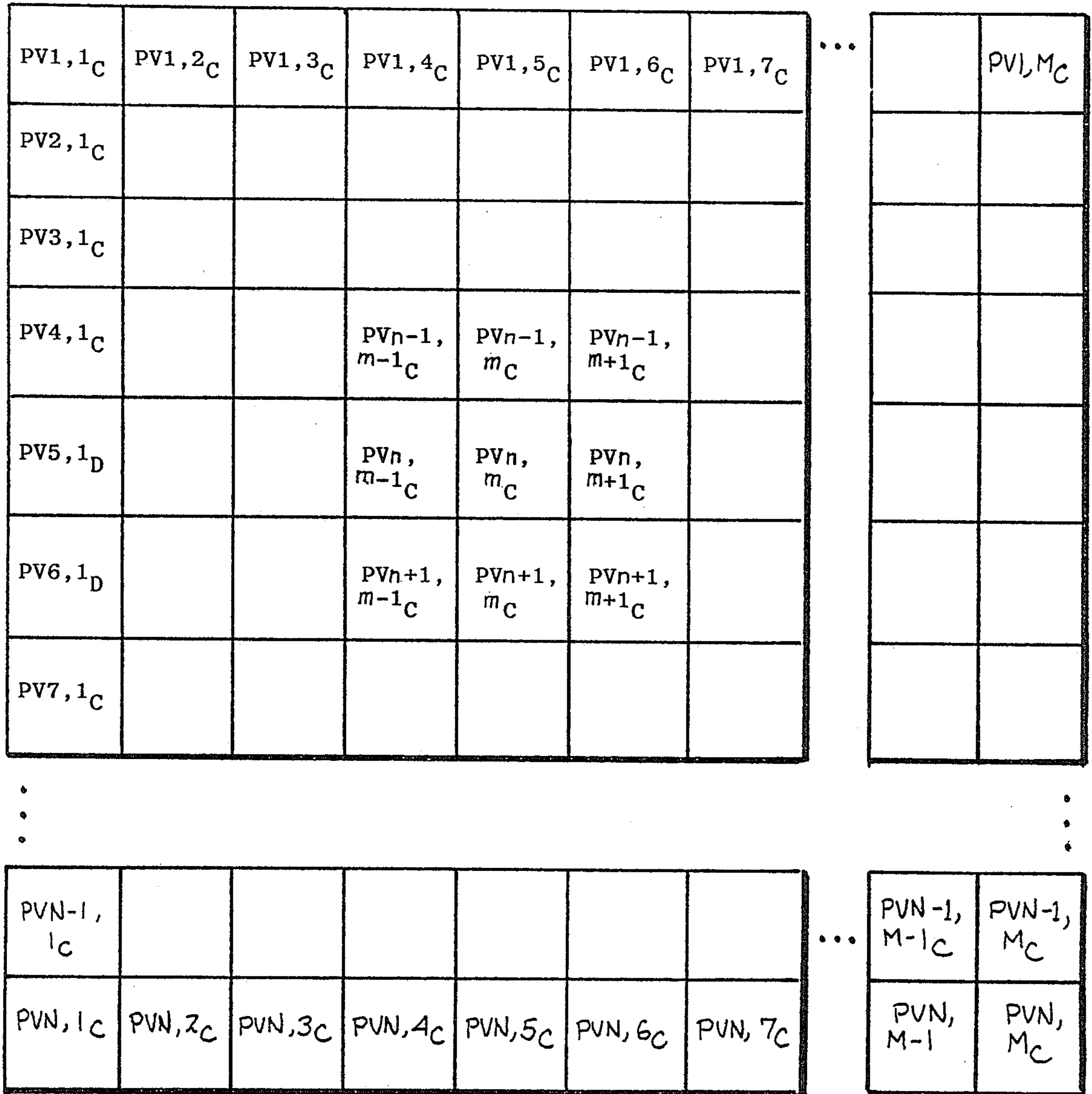


Fig. 30



CCA ↗

Fig. 31

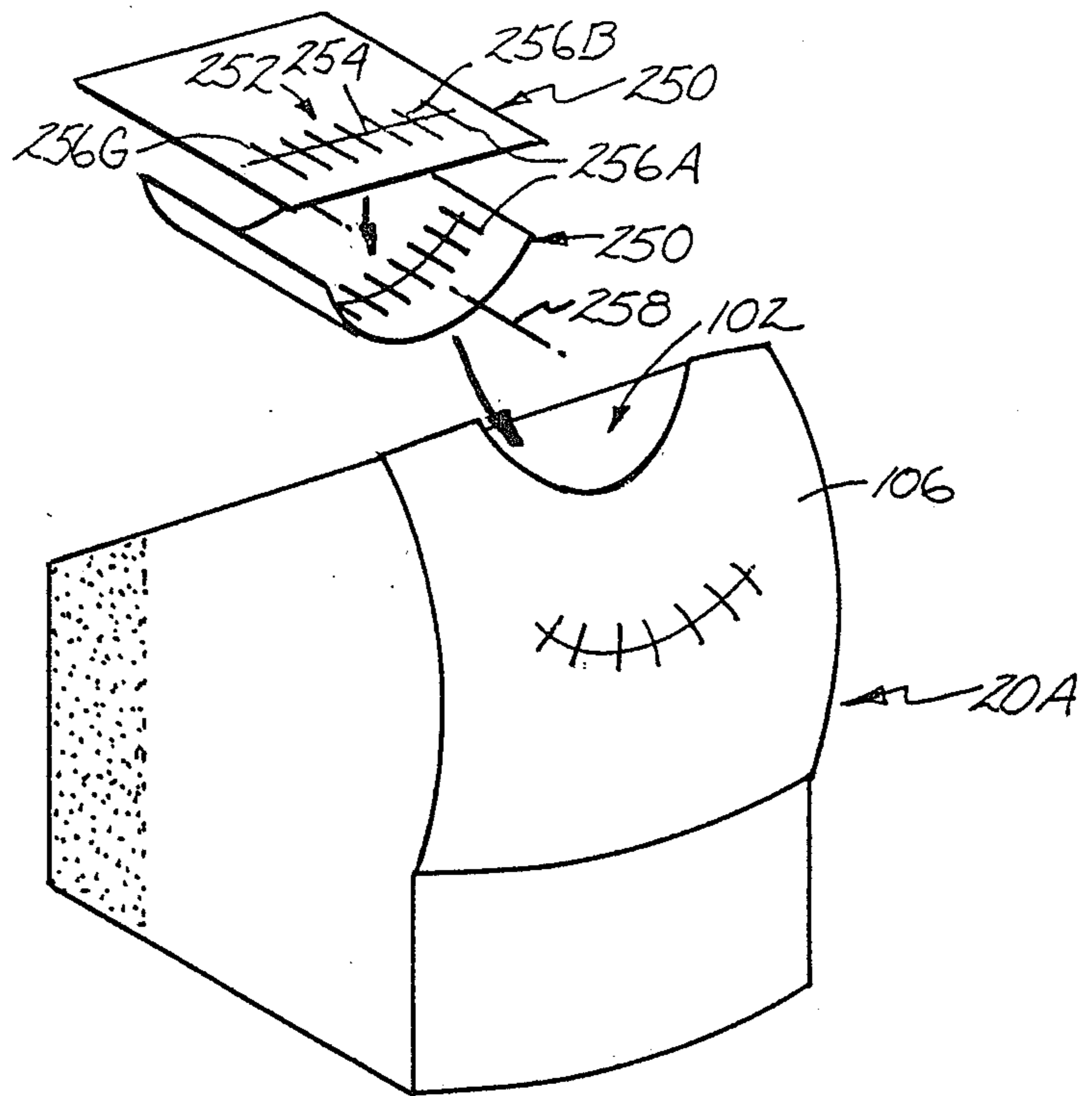


Fig. 32

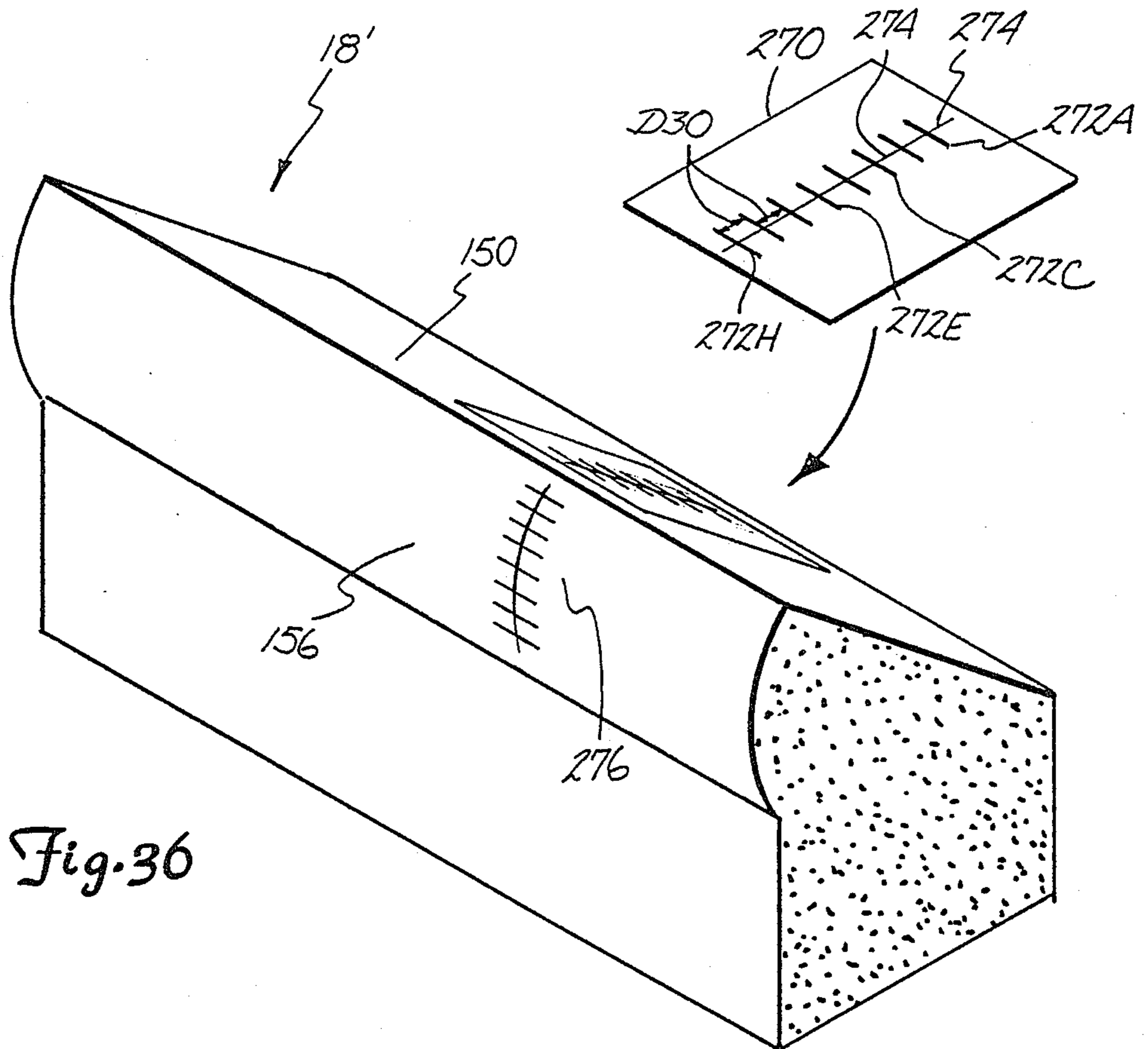


Fig. 36

Fig. 33

Curvature Correction Table	
OFF 1	7
OFF 2	7
OFF 3	6
OFF 4	6
OFF 5	5
OFF 6	5
OFF 7	4
OFF 8	4
OFF 9	3
OFF 10	3
...	...
OFF m	...
OFF M	...

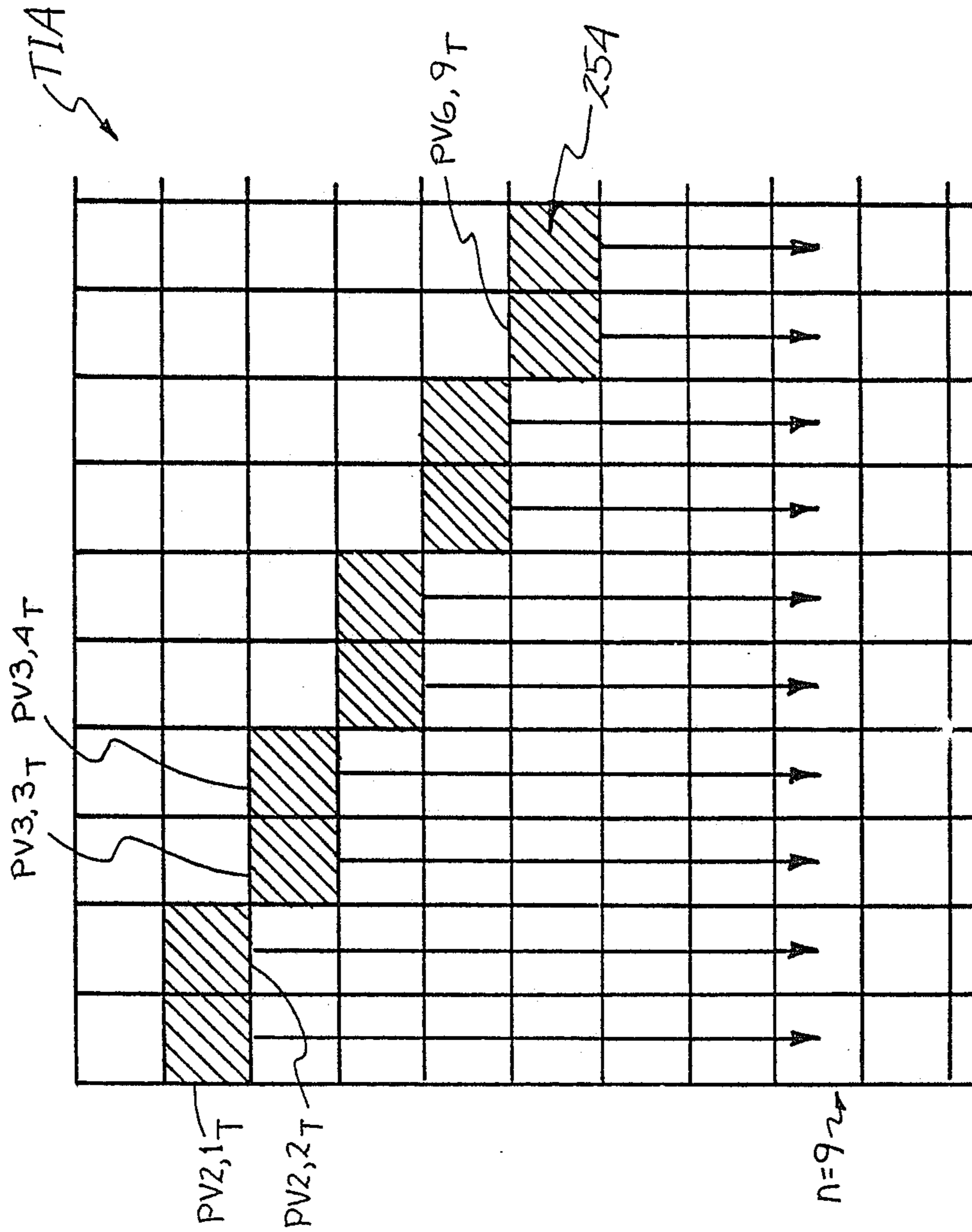
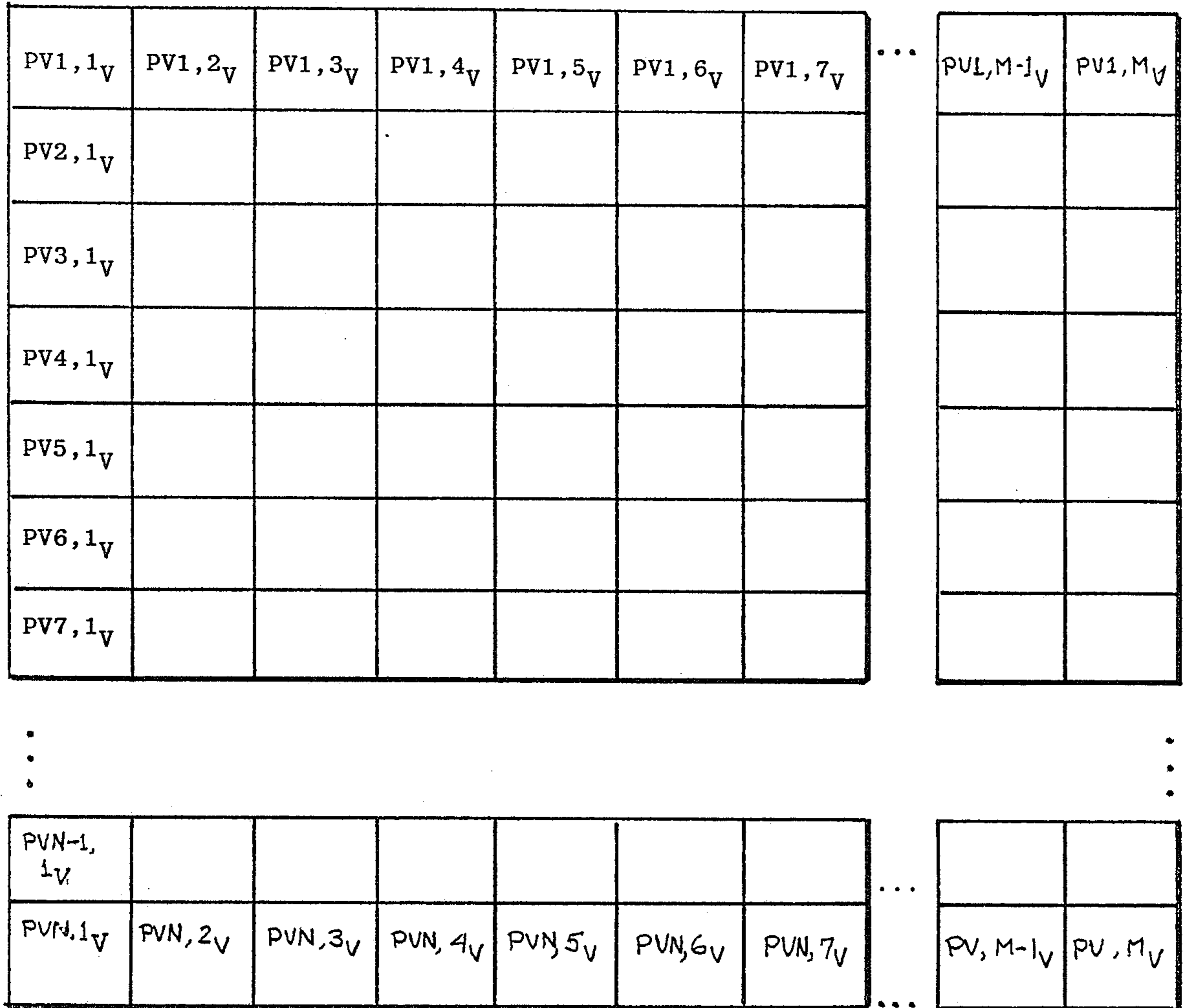


Fig. 34



VA ↗

Fig. 35

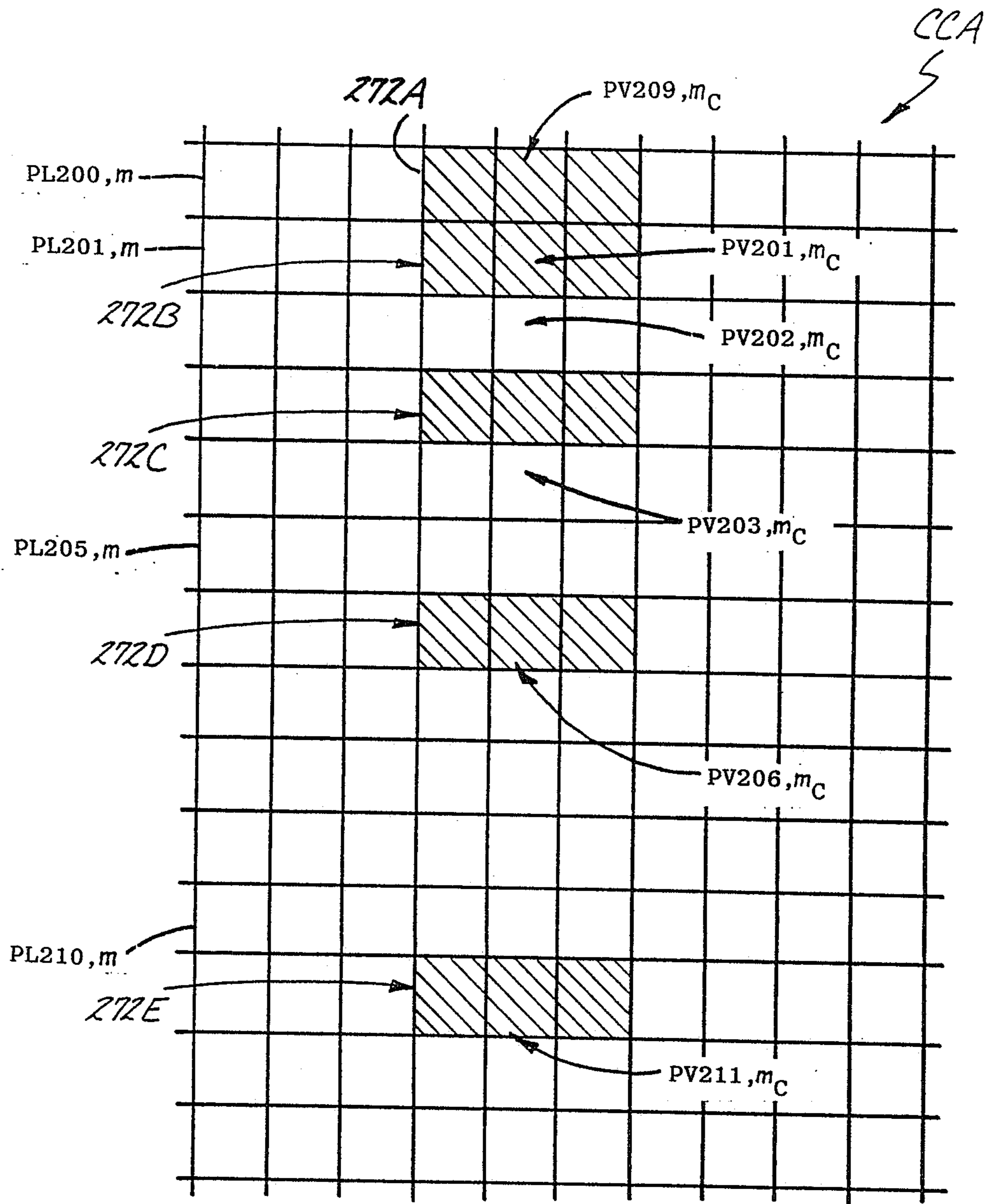


Fig.37

HORIZONTALLY SCALED ARRAY HA	VERTICALLY SCALED ARRAY VA
PVn,1 _H	PVMAX
PVn,2 _H	PVMAX
⋮	⋮
PVn,300 _H	PVn,300 _V
PVn,301 _H	PVn,301 _V
PVn,302 _H	PVn,301 _V
PVn,303 _H	PVn,301 _V
PVn,304 _H	PVn,301 _V
PVn,305 _H	PVn,302 _V
PVn,306 _H	PVn,302 _V
PVn,307 _H	PVn,302 _V
PVn,308 _H	PVn,303 _V
PVn,309 _H	PVn,304 _V
PVn,310 _H	PVn,305 _V
PVn,311 _H	PVn,305 _V
PVn,312 _H	PVn,306 _V
PVn,313 _H	PVn,307 _V
PVn,314 _H	PVn,309 _V
PVn,315 _H	PVn,310 _V
PVn,316 _H	PVn,311 _V
⋮	⋮
PVn,M-1 _H	PVMAX
PVn,M _H	PVMAX

Fig. 40

VERTICALLY SCALED ARRAY VA	CURVATURE CORRECTED ARRAY CCA
PV1,m _V	PVMAX
PV2,m _V	PVMAX
⋮	⋮
PV200,m _V	PV200,m _C
PV201,m _V	PV201,m _C
PV202,m _V	PV201,m _C
PV203,m _V	PV201,m _C
PV204,m _V	PV201,m _C
PV205,m _V	PV202,m _C
PV206,m _V	PV202,m _C
PV207,m _V	PV202,m _C
PV208,m _V	PV203,m _C
PV209,m _V	PV204,m _C
PV210,m _V	PV205,m _C
PV211,m _V	PV205,m _C
PV212,m _V	PV206,m _C
PV213,m _V	PV207,m _C
PV214,m _V	PV209,m _C
PV215,m _V	PV210,m _C
PV216,m _U	PV211,m _C
⋮	⋮
PVN-1,m _V	PVMAX
PVN,m _V	PVMAX

Fig. 38

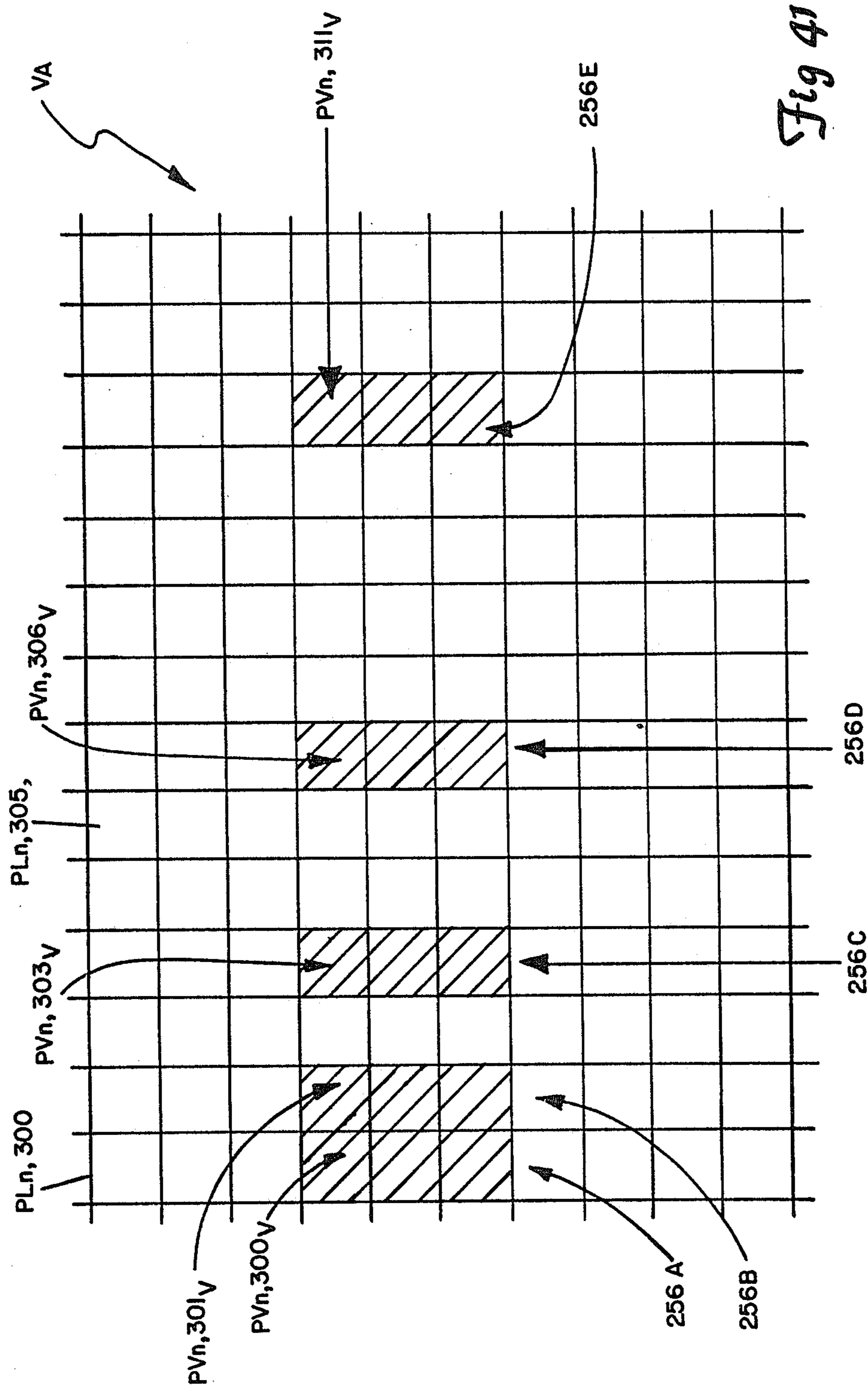
280

310

$PV1, 1_H$	$PV1, 2_H$	$PV1, 3_H$	$PV1, 4_H$	$PV1, 5_H$	$PV1, 6_H$	$PV1, 7_H$	$PV1, M-1_H$	$PV1, M_H$
$PV2, 1_H$								
$PV3, 1_H$								
$PV4, 1_H$			$PVn-1, m-1_H$	$PVn-1, m_H$	$PVn-1, m+1_H$			
$PV5, 1_H$			$PVn, m-1_H$	PVn, m_H	$PVn, m+1_H$			
$PV6, 1_H$			$PVn+1, m-1_H$	$PVn+1, m_H$	$PVn+1, m+1_H$			
$PV7, 1_H$								
$PVN-1, 1_H$							$PVN-1, M-1_H$	$PVN-1, M_H$
$PVN, 1_H$	$PVN, 2_H$	$PVN, 3_H$	$PVN, 4_H$	$PVN, 5_H$	$PVN, 6_H$	$PVN, 7_H$	$PVN, M-1_H$	PVN, M_H

Fig. 39

HA ↗



TENPRINTER Data Capture System

- 1. Clear system for new card.
- 2. Start fingerprint capture.
- 3. Enter/change demographic function.
- 4. Print card.
- 5. Options.

300
↙

Enter number, then press RETURN key:

Fig.42

FIG 40

TENPRINTER Fingerprint Processing Choices

- 0. Exit.
- 1. Capture Prints.
- 2. Recapture Prints.
- 3. Options.

Fig.46

Enter number, then press RETURN key:

FIG 41

Name: Last _____	First _____	Middle _____
Date of Birth (DOB) _____	Place of Birth _____	
Sex _____	Race _____	Hgt _____ Wgt _____ Eyes _____ Hair _____
Aliases _____	Contributor (ORI) _____	
Your no. (OCA) _____	FBI no. (FBI) _____	
SID no. (SID) _____	Social Security no. (SOC) _____	
Today's date _____	Date Arrested or Received (DOA) _____	
Charge _____	Final Disposition _____	

Fig.45

Fig. 47

DEPARTMENT INFORMATION				DEMOGRAPHIC INFORMATION			
R. THUMB	R. INDEX	R. MIDDLE	R. RING	R. LITTLE			
L. THUMB	L. INDEX	L. MIDDLE	L. RING	L. LITTLE			
LEFT FOUR FINGERS SIMULTANEOUSLY				L. THUMB	R. THUMB	RIGHT FOUR FINGERS SIMULTANEOUSLY	

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METHODS FOR DIGITALLY NOISE AVERAGING AND ILLUMINATION EQUALIZING FINGERPRINT IMAGES

Reference is hereby made to co-pending applications entitled Optical Fingerprinting System and Optical Devices for Providing Fingerprint Images, filed on even date herewith.

BACKGROUND OF THE INVENTION

1. Field of the Invention.

The present invention relates to computer processing of fingerprint images

2. Description of the Prior Art.

Over the years, the most commonly used technique for obtaining fingerprints has been to apply ink to the tip of individual fingers and roll the inked fingertip at an appropriate location on an applicant card to produce the "rolled" fingerprint. Plain or "slap" prints, which are the simultaneous fingerprinting of the index, middle, ring, and little fingers of a hand, are taken by inking the tips of these fingers and simultaneous pressing the inked fingertips on the applicant card at the appropriate location. While these inking procedures will usually provide satisfactory images, they have their drawbacks. The inking procedure is messy. Several attempts are often required in order to obtain an acceptable fingerprint. Perhaps even a bigger drawback of this system is that the printed images are not easily adaptable to computerized storage and processing techniques, inhibiting cooperation and fingerprint data transfer between various police agencies.

Optical fingerprinting systems which optically generate fingerprint images are also in use. Several such optical fingerprinting systems are disclosed in the U.S. Pat. Nos. to Becker 3,482,498, McMahon 3,975,711, White 3,200,701, Schiller 4,544,267 and Marcus 4,553,387. However, for a variety of reasons, systems such as these have not gained widespread acceptance.

Due to the compound curved nature of the fingerprint on a finger, it is difficult to optically obtain an image corresponding to a rolled fingerprint. The Schiller U.S. Pat. No. 4,544,267 discloses an apparatus in which a finger pressed against a platen provides a fingerprint object which is scanned by an interrogating beam of collimated light that is linearly displaced across the platen thereby maintaining a constant angle between the interrogating light beam and the plane of the object being scanned. The Marcus U.S. Pat. No. 4,553,837 discloses finger processing apparatus which includes a cylindrical-segment platen which supports a finger. Optical scanning equipment scans the circumference of the platen in such a manner that the angle of incidence of a light beam on the fingerprint object remains constant. The Becker U.S. Pat. No. 3,482,498 discloses several embodiments of an optical apparatus for producing a rolled fingerprint image, both of which utilize a prism having a totally reflecting surface. The embodiment shown in FIG. 1a utilizes a plurality of prisms and light sources, and produces only an approximation of the ball and side ridges. The embodiment shown in FIGS. 2 and 3 utilize a mechanical system actuated by a rolling finger to move and position a light source.

While the fingerprinting systems disclosed in the Schiller and Marcus patents, and the second embodiment disclosed in the Becker patent, may be capable of optically providing a rolled fingerprint image, these

systems are less than wholly desirable. Perhaps most important, it is not possible to review the image being captured in real-time to determine whether or not critical information required for classification is being captured. Furthermore, the mechanical aspects of these systems, are relatively complicated. As a result, maintaining focus during the time required to obtain the entire rolled fingerprint image can be difficult. Although the fingerprint image produced by the first embodiment of the invention disclosed in the Becker patent provides an image in real-time, this image only approximates the rolled fingerprint image.

Prisms such as those disclosed in the McMahon U.S. Pat. No. 3,975,711 and the White U.S. Pat. No. 3,200,701 utilize the optical principle of total internal reflection to produce a fingerprint image. As such, the "plane" of the fingerprint must be imaged at an observation angle which is not perpendicular to the plane. Vertical scale errors, or distortions of distances on the fingerprint image from their true distances along a Y-axis which is generally parallel to a longitudinal axis of the finger, are therefore inherent. When the surface of the prism on which the finger is inserted is grooved as illustrated in the McMahon patent, horizontal scale errors which are distance distortions on the fingerprint image from true distances along a X-axis generally perpendicular to the longitudinal axis of the finger on the fingerprint, are also inherent. Furthermore, curvature errors are also produced. As a result of the vertical and horizontal scale errors, and the curvature errors inherent in the use of a grooved total internal reflection prism such as that shown in McMahon, the fingerprint image provided thereby is severely distorted from a true rolled fingerprint of the same finger.

Prisms which have grooved finger receiving surfaces such as those disclosed in the McMahon patent will not provide optimum surface contact between the surface of a finger and therefore its fingerprint, and the prism. Portions of the fingerprint which it may be desired to obtain will therefore be lost. Illumination of the fingerprint through prisms such as that shown in the McMahon patent is often unequal, resulting in an image which has varying intensities throughout its area. Furthermore the contrast between ridges and valleys in the fingerprint image produced by these prisms is generally relatively low.

Many police departments including the FBI require both plain or slap fingerprint images and individual rolled fingerprint images as part of their standard fingerprinting process. Prior art optical fingerprinting systems, however, are incapable of optically generating both individual rolled fingerprints and slap fingerprint images.

It is evident that there is a continuing need for improved optical fingerprinting systems. A system having the capability of capturing both slap and rolled fingerprint images would be especially desirable. An operator should be able to easily interface with the system, and observe in real-time the quality of the fingerprint image before it is captured. A system which can capture fingerprints from fingers of varying sizes would also be useful.

It is also evident that there is room for improvement in the prisms utilized by optical fingerprinting systems. Grooves in these prisms should be contoured in a manner which permits optimum contact between the fingerprint and grooved surface. A prism which can capture slap fingerprint images is also needed. A prism which

reduces horizontal and vertical scale errors, as well as curvature errors, would also be welcomed. Furthermore, a prism which produces a high contrast fingerprint image is also needed. Other techniques which can correct for vertical and horizontal scale errors, and curvature errors so as to produce an enhanced fingerprint image would also be desirable properties of an optical fingerprinting system.

SUMMARY OF THE INVENTION

The present invention is a method of operating programmable computing means to enhance fingerprint images. Using a noise average method, input pixel values of an array of input pixel values characteristic of the fingerprint image are processed to produce a noise averaged array of pixel values characteristic of a noise averaged image. An input array of pixel value characteristic of a fingerprint image is received. Noise averaging subarrays of input pixel values are selected. Each subarray includes an input pixel value to be noise averaged, and a plurality of input pixel values adjacent the pixel value to be noise averaged. Noise averaged pixel values are generated as a function of a weighted average of the input pixel values in the noise averaging subarrays. The noise averaged pixel values are then stored as an array of noise averaged pixel values characteristic of the image.

Using an illumination equalizing method, input pixel values of an array of input pixel values characteristic of a fingerprint image are processed to produce an illumination equalized array of pixel values characteristic of an illumination equalized image. An array of input pixel values characteristic of a fingerprint image is received. Equalizing subarrays of input pixel values are selected. Each subarray includes an input pixel value to be illumination equalized. Subarray average values are generated as a function of the pixel values within the equalizing subarrays. The subarray average values are subtracted from the corresponding pixel values being equalized to generate pixel difference values. A predetermined constant is added to the pixel difference values to generate intermediate illumination equalized pixel values. If intermediate illumination equalized pixel values are less than a predetermined minimum pixel value, the corresponding illumination equalized pixel values are set equal to the minimum pixel value. If intermediate illumination pixel values are greater than or equal to the minimum pixel value, and less than or equal to a predetermined maximum pixel value, the corresponding illumination equalized pixel values are set equal to the corresponding intermediate illumination equalized pixel values. If the intermediate illumination equalized pixel values are greater than the maximum pixel value, the corresponding illumination equalized pixel values are set equal to the maximum pixel value.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates elements of an optical fingerprinting system in accordance with the present invention.

FIG. 2 is a view looking into the top of the optics/processor unit shown in FIG. 1.

FIG. 3A is a side view of the optics subsystem shown in FIG. 2, illustrating the optical propagation of fingerprint images from the finger prism to the camera when the slap/image selection optics is positioned at its finger image position.

FIG. 3B is a side view of the optics subsystem shown in FIG. 2 illustrating the optical propagation of finger-

print images from the slap prism to the camera when the slap/image selection optics is positioned at its slap image position.

FIG. 4 is a detailed perspective view of the lens trolley shown in FIG. 2.

FIG. 5 is a detailed view of the fastening assembly shown in FIG. 2.

FIG. 6 is a perspective view of an individual finger prism shown in FIG. 2.

FIG. 7 is a sectional view of the finger prism shown in FIG. 6.

FIG. 8 is a rear view of the finger prism shown in FIG. 6.

FIG. 9 is a side view of the finger prism shown in FIG. 6.

FIG. 10 is a top view of the finger prism shown in FIG. 6.

FIG. 11 is a bottom view of the finger prism shown in FIG. 6.

FIG. 12 is a graphic representation of the optical properties of the finger prism shown in FIG. 6, when a finger is not positioned within its groove.

FIG. 13 is a graphic representation of the optical properties of the prism shown in FIG. 6, when a finger is positioned within its groove.

FIG. 14 is a detailed view of a portion of the prism and finger shown in FIG. 13, graphically illustrating the optical properties of the prism in conjunction with a finger positioned thereon.

FIG. 15 is a graphic representation of a finger illustrating various characteristics of a fingerprint thereon.

FIG. 16 is a perspective view of an alternative embodiment of the slap print prism shown in FIG. 2.

FIG. 17 is a side view of the slap print prism shown in FIG. 16.

FIG. 18 is a perspective view of the slap print prism shown in FIG. 2.

FIG. 19 is a side view of the slap print prism shown in FIG. 18.

FIG. 20 is a block diagram representation of the processor subsystem of the optics/processor unit shown in FIG. 1, and illustrating its interconnection to other electrical elements of the fingerprinting system.

FIG. 21 is a graphic representation of an image array of image pixel values generated by the frame digitizer shown in FIG. 20.

FIG. 22 is a graphic representation of a noise averaged array of noise averaged pixel values generated by the processor subsystem shown in FIG. 20.

FIG. 23 is a graphic representation of an illumination equalized array of illumination equalized pixel values generated by the processor subsystem shown in FIG. 20.

FIG. 24 is a graphic representation of the noise averaged array, illustrating a subarray of pixel values utilized by the processor subsystem to generate the illumination equalized array.

FIG. 25 is a graphic representation of a directional filtered array of directional filtered pixel values produced by the processor subsystem shown in FIG. 20.

FIG. 26 is a graphic representation of an illumination equalized array illustrating the regular and offset subarrays utilized by the processor subsystem shown in FIG. 20 to produce the directional filtered array.

FIG. 27 is a detailed graphic representation of an illumination equalized array such as that shown in FIG. 26, illustrating the regular and offset subarrays utilized

by the processor subsystem shown in FIG. 20 to produce the directional filtered array.

FIG. 28 is a graphic representation of a fingerprint image showing artifacts or hairs therein.

FIG. 29 is a graphic representation of an unhaired array of unhaired pixel values produced by the processor subsystem shown in FIG. 20.

FIG. 30 is a graphic representation of a directional filtered array illustrating a portion of a fingerprint image having an artifact or hair therein.

FIG. 31 is a graphic representation of a curvature corrected array of curvature corrected pixel values generated by the processor subsystem shown in FIG. 20.

FIG. 32 is a view illustrating a template having a pattern of indicia thereon, and an image of the pattern of indicia when the template is positioned on the finger prism shown in FIG. 6.

FIG. 33 is a graphic representation of a curvature correction table of curvature correction data generated and used by the processor subsystem shown in FIG. 20 to produce the curvature corrected array shown in FIG. 31.

FIG. 34 is a graphic representation of a template image array of template image pixel values generated by the processor subsystem shown in FIG. 20 and representing an image of the pattern of indicia shown in FIG. 32.

FIG. 35 is a graphic representation of a vertically scaled array of vertically scaled pixel values generated by the processor subsystem shown in FIG. 20.

FIG. 36 is a view illustrating a template having a pattern of indicia thereon, and an image of the pattern of indicia when the template is positioned on the slap print prism shown in FIG. 16.

FIG. 37 is a graphic representation of a curvature corrected array generated by the processor subsystem shown in FIG. 20 and representative of the image of the pattern of indicia shown in FIG. 36.

FIG. 38 is a graphic representation of a table of vertical scale correction data generated by the processor subsystem from the curvature corrected array shown in FIG. 37, and used to generate a vertically scaled array.

FIG. 39 is a graphic representation of a horizontally scaled array of horizontally scaled pixel values generated by the processor subsystem shown in FIG. 20.

FIG. 40 is a graphic representation of a table of horizontal scale correction data generated by processor subsystem from the image of the pattern of indicia shown in FIG. 32 and used to produce the vertically scaled array shown in FIG. 39.

FIG. 41 is a graphic representation of a vertically scaled array representative of the image of the pattern of indicia shown in FIG. 32.

FIG. 42 is an illustration of a Main Display menu generated and displayed by the data terminal shown in FIG. 1.

FIG. 43 is a detailed view of the display on the optics/processor unit shown in FIG. 1.

FIG. 44 is a detailed view of the key pad on the optics/processor unit shown in FIG. 1.

FIG. 45 is an illustration of a Demographic/Department Information menu generated and displayed by the data terminal shown in FIG. 1.

FIG. 46 is an illustration of a Processing Choices menu generated and displayed by the data terminal shown in FIG. 1.

FIG. 47 is a graphic representation of a booking or applicant card onto which fingerprint images, department information and demographic information can be printed by the printer shown in FIG. 1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Overall System and Optics Subsystem Description

An optical fingerprinting system 10 in accordance with the present invention is illustrated generally in FIG. 1. As shown, fingerprinting system 10 includes an optics/processor unit 12, video monitor 14, printer 16, and data terminal 6, which includes a keyboard 7 and monitor 8. Data terminal 6, monitor 14 and printer 16 are interfaced to optics/processor unit 12. Fingerprinting system 10 is capable of providing printed records of both plain or "slap" prints which are simultaneous impressions of the fingerprints of all fingers of a hand other than the thumb, and individual fingerprints.

To take a slap print, the person to be fingerprinted will position the fingertips of their index, middle, ring and little fingers on slap print prism 18'. Optics/processor unit 12 images the slap print and provides a real-time visual display thereof on monitor 14. When an operator observes a satisfactory slap print image on monitor 14, a key 17A-17D on key pad 19 is actuated causing optics/processor unit 12 to "freeze" the image by storing digital data representative thereof. This image is then enhanced when the digital data is processed by optics/processor unit 12 in accordance with image enhancement software. Data representative of the enhanced image is then stored. If it is desired to fingerprint an individual finger, the person to be fingerprinted will position their finger within groove 102 of an individual finger prism such as 20A. Optics/processor unit 12 will image the fingerprint, and provide a display thereof on monitor 14. This image can then be "frozen", and data representative thereof processed by optics/processor unit 12 and stored.

Demographic data characteristic of the person being fingerprinted and department data (or other relevant information) utilized by the organization doing the fingerprinting can be entered into system 10 by the operator through keyboard 7. This data, along with the stored fingerprint images, can then be printed at proper locations on a document such as a standard booking or applicant card 15 by printer 16. These procedures are all facilitated by system generated menus and prompts which are displayed on monitor 8 of data terminal 6, as well as by display 13 and illumination of buttons 17A-17D of key pad 19.

An optics subsystem 22 within optics/processor unit 12 is illustrated in greater detail in FIGS. 2, 3A and 3B. Optics subsystem 22 includes slap print prism 18', finger prism trolley 24, first slap image mirror 25, slap/finger image selection optics 26, and a sensor such as video camera 28. Slap print prism 18' is mounted in such a manner that its finger-receiving surface 150 is generally level and coplanar with a stepped top panel 32 of unit 12. First slap image mirror 25 is mounted with respect to slap print prism 18' so as to receive slap fingerprint images projected from image projection surface 156 of the prism, and to reflect these images to slap/finger image selection optics 26. Slap print prism 18' is illuminated by means of a light source such as lamp 31 which is positioned adjacent to a light-receiving surface 162 of the prism. In the embodiment shown, lamp 31 is a side-

ways oriented U-shaped fluorescent bulb having two legs which are shown in cross section. The two legs of lamp 31 extend across light-receiving surface 162 of prism 18', and are surrounded on a side opposite prism 18' by reflector 32.

Finger prism trolley 24, which is illustrated in greater detail in FIG. 4, includes a base 34 to which a plurality of individual finger prisms 20A-20D are mounted by screws or other suitable fasteners (not shown). Base 34 includes a track-follower section 36 which is slidably received upon a guide track 37. Guide track 37, in turn, is mounted with respect to a sloping front panel 38 of unit 12 by means of a mounting bracket 39. As shown in FIGS. 2 and 4, each finger prism 20A-20D has an upper surface 100 which includes a finger-receiving groove 102. Prisms 20A-20D are spaced from one another by triangular shaped mirror blocks 40 which have reflective or mirror side surfaces 41 which angle away from side surfaces 112 of prisms 20A-20D and intersect at a point toward slap/finger image selection optics 26. End mirror blocks 42 are positioned adjacent side surfaces 112 of prisms 20A and 20D which are opposite mirror blocks 40. End mirror blocks 42 also have a reflective side surface 43 which angles away from side surfaces 112 in a direction toward slap/finger selection optics 26. Mirror blocks 40 have their top surface covered by cover plates 44 (some of which are shown in phantom in FIG. 2) which extend between adjacent prisms 20A-20D.

Finger prism trolley 24 is mounted with respect to unit 12 at an angle in such a manner that finger-receiving grooves 102 of prisms 20A-20D are generally parallel with top panel 50 of the unit. As perhaps best shown in FIGS. 1, 3A and 3B, a finger-receiving cutout or aperture 51 extends through top panel 50 and sloping side panel 38 at a position adjacent trolley 24 to expose groove 102 of one of prisms 20A-20D. By means of trolley handle 52 which extends through panel 38, an operator can slide trolley 24 along guide track 37 in such a manner as to position groove 102 of a desired finger prism 20A-20D adjacent aperture 51. A lamp 53, which can be identical to lamp 31 previously described, is mounted with respect to unit 12 below aperture 51 and adjacent a light-receiving surface 104 of whichever prism 20A-20D has been positioned adjacent aperture 51. Light from lamp 53 will directly enter light-receiving surface 104, and be reflected by surfaces 41 and 43 of mirror blocks 40 and 42, respectively, into side walls 112 of the selected finger prism 20A-20D. A fingerprint image of a finger positioned within groove 102 of the selected prism 20A-20D will thereby be propagated from image propagation surface 106 toward slap/finger image selection optics 26.

Slap/finger image selection optics 26 includes a mounting plate 60 which has a second slap image mirror 61 and a slap image focusing lens assembly 62, as well as a finger image mirror 63 and finger image focusing lens assembly 64 mounted to a lower side thereof. Finger image mirror 63 is mounted to mounting plate 60 by means of mounting brackets 65, and is oriented at an angle so as to receive fingerprint images propagated from one of finger prisms 20A-20D and to reflect the fingerprint image to a lens (not separately visible) within finger image focus lens assembly 64. Lens assembly 64 is mounted to mounting plate 60 by means of mounting bracket 66. Second slap image mirror 61 is mounted to mounting plate 60 by mounting brackets 67 at a position adjacent finger image mirror 63. Mirror 61

is oriented at such an angle as to receive slap print images from first slap image mirror 25, and to reflect these images to a lens (not separately visible) within lens assembly 62. Lens assembly 62 is mounted to mounting plate 60 by means of mounting bracket 68. The lenses within lens assemblies 62 and 64 can be adjustably positioned along their optical axis to facilitate optical focusing adjustments of subsystem 22.

As shown in FIG. 2, a motor mounting bracket 70 is mounted to a left side panel 71L of unit 12, while a support bracket 72 is mounted to right side panel 71R. Mounted to and extending between brackets 70 and 72 is a pair of guide rods 73. Guide rods 73 are mounted to brackets 70 and 72 by means of fasteners 74 in the embodiment shown. Mounting plate 60 is slidably suspended from guide rods 73 by means of slide bushings 75A-75C.

A motor 76 which is interfaced to processor subsystem 30 is mounted to a lower face (not visible) of mounting bracket 70, and has a drive shaft 77 which extends through the bracket. A drive wheel 78 is mounted to shaft 77. An idler wheel 79 is rotatably mounted to an idler bracket 99. Idler bracket 99 is mounted across guide rods 73.

Looped between drive wheel 78 and idler wheel 79 is a drive belt 80.

A flexible fastening assembly 81 for flexibly fastening belt 80 to mounting plate 60 is illustrated in FIG. 5. Fastening assembly 81 includes a clamp 82 which has a slot (FIG. 2) into which drive belt 80 is fixedly clamped. Clamp 82 also has a pair of downward extending arms 83 on its opposite sides. Ends of a flexible member such as stretched spring 84 are fastened to arms 83. A central portion of spring 84 is fastened to mounting plate 60 by means of clamp or bracket 85.

Motor 76 is interfaced to a processor subsystem 30 of optics/processor unit 12. In response to finger prism select signals from processor subsystem 30, motor 76 will rotate in a clockwise direction as viewed in FIG. 2, thereby driving mounting plate 60 (slap/finger image selection optics 26) along guide rods 73 to a rightmost or finger prism select position illustrated in FIGS. 2 and 3A. Mounting plate 60 is driven in this manner until slide bushing 75B is positioned against adjustable stop 86 and actuates microswitch 87. Microswitch 87 is interfaced to processor subsystem 30, and provides signals representative of the positioning of mounting plate 60 to the finger prism select position.

With slap/finger image selection optics 26 in the finger prism select position, video camera 28, finger prism focus lens assembly 64, and finger image mirror 63 are all aligned with the finger prism 20A-20D which has been positioned adjacent aperture 51. Visual images of fingerprints of fingers positioned with groove 102 will thereby be propagated from image propagation surface 106 of the selected prism 20A-20D along finger image optical path 88, reflected by mirror 63, focused by the lens within assembly 64, and imaged by camera 28.

In response to slap print prism select signals from processor subsystem 30, motor 76 will rotate in a counterclockwise direction, thereby pulling mounting plate 60 and slap/finger image selection optics 26 to a slap print select or leftmost position (not shown) when viewed from FIG. 2. Slide bushing 75C will then actuate microswitch 89, which in turn provides slap print positioning select signals to processor subsystem 30. Processor subsystem 30 then stops rotation of motor 76.

As illustrated in FIG. 3B, when selection optics 26 are properly positioned in the slap print select position, second slap image mirror 61 and slap print focusing lens assembly 62 will be aligned about a slap print optical path 90 between slap print prism 18', first slap image mirror 25, and camera 28. Slap print images of fingers positioned on slap print prism 18' will thereby be propagated from image propagation surface 156 of the prism along slap print optical path 90, reflected by mirrors 25 and 61, focused by the lens within assembly 62, and imaged by camera 28. Video signals representative of fingerprint images imaged by camera 28 are provided to processor subsystem 30. Key pad 19 is illustrated in FIGS. 1, 20, and 44. As perhaps best illustrated in FIG. 44, key pad 19 is formed by a YES key 17A, a NO key 17B, a CAPTURE key 17C, and an amputee or AMP Key 17D. Keys 17A-17D are preferably fabricated of a translucent material such as plastic, and have a light source such as LEDs 21A-21D, respectively, positioned thereunder. LEDs 21A-21D are each individually interfaced to processor subsystem 30 as shown, and can be individually lit or illuminated by the processor subsystem.

Display 13 is illustrated in greater detail in FIG. 43. As shown, display 13 includes a left hand representation or indicia 312, and a right hand indicia 314. Each finger of indicia 312 and 314 have a light such as LEDs 316A-316E and 318A-318E associated therewith. In the embodiment illustrated in FIG. 43, LEDs 316A-316E are positioned in the thumb, index, middle, ring, and little fingers of left hand indicia 312. Leds 318A-318E are positioned in the thumb, index, middle, ring and little fingers of right hand indicia 314. Leds 316A-316E and 318A-318E are each interfaced (FIG. 20) individually to processor subsystem 30 so as to be capable of individual illumination thereby.

Individual Finger Prisms

Individual finger prism 20A, which is representative of individual finger prisms 20A-20D, is perhaps best described with reference to FIGS. 6-11. Prism 20A is an optical device fabricated of light-propagating material such as plastic which is characterized by an index of refraction. In one embodiment, prisms 20A-20D are machined from acrylic polymer, although they can also be molded from this or other materials.

As shown, prism 20A has a first or sloping upper surface 100 which has a finger-receiving groove 102 therein, and a front face which includes both a second or light-receiving surface 104 and a third or image propagation surface 106. Prism 20A also includes a fourth or bottom surface 108, a fifth or back surface 110, and two side faces or surfaces 112.

Prism 20A has a width of dimension D1, and an overall depth of dimension D2. Back surface 110 is perpendicular to bottom surface 108 and extends to a height of dimension D3 from the bottom surface. Upper surface 100 intersects back surface 110 at an angle A1 with respect to bottom surface 108. Light-receiving surface 104 extends perpendicularly from bottom surface 108 to a height of dimension D4. The magnitude of angle A1 will depend upon the index of refraction of the material from which prism 20A is manufactured. In one preferred embodiment in which prism 20A is manufactured of acrylic polymer, angle A1 is 35°. In this same embodiment, dimensions D1-D4 are 1.58 inches, 2.35 inches, 1.62 inches, and 0.95 inches, respectively.

As shown in FIGS. 6, 7, 8, and 10, groove 102 is elongated and contoured to receive a finger. Groove 102 includes both a fingerbody portion 113 and a fingertip portion 114. Fingerbody portion 113 and fingertip portion 114 of groove 102 both include a bottom wall 116 and side walls 118. As best shown in FIG. 7, the deepest part of bottom wall 116 of fingerbody portion 113 is at a constant depth of dimension D8 with respect to upper surface 100. The deepest part of bottom wall 116 of fingertip portion 114 slopes from its intersection with fingerbody portion 113 toward upper surface 100 at an angle A5 (45° in one embodiment) with respect to bottom surface 108. In the embodiment shown in FIG. 7, bottom wall 116 curves between portions 113 and 114 at a radius of curvature defined by dimension D6. In one preferred embodiment, dimension D6 is a 2.00 inch radius of curvature. This radius of curvature (dimension D6) is centered at a point displaced from the intersection of upper surface 100 and back surface 110 by length of dimension D7. Following the embodiment described above, dimension D8 is 0.50 inches while dimension D7 is 0.72 inches.

As perhaps best shown in FIG. 5, bottom wall 116 of groove 102 is semicircular having a radius of curvature characterized by dimension D8. This radius of curvature (dimension D8) can be constant throughout the length of groove 102. Side walls 118 are preferably planar, and form an angle A2 with respect to side surfaces 112 which are perpendicular to both upper surface 100 and bottom surface 108 of prism 20A. In one preferred embodiment, angle A2 is 22½°.

The above-described characteristics of groove 102 have been found to permit the highest or optimum degree of contact between a finger (not shown in FIGS. 6-11) and the various surfaces of the groove. This feature is especially important for fingertip portion 114 of groove 102 so that an image of the largest possible area of the fingerprint on the tip of a finger is propagated from prism 20A. Dimensions D6, D7 and D8, as well as angle A2, will of course vary depending upon the size of the finger to be received by groove 102. As shown in FIGS. 2 and 4, the size of grooves 102 of each prism 20A-20D on trolley 24 is different so that a prism having a properly sized groove 102 can be selected as needed for the particular finger of a particular person being fingerprinted. In general, the larger the finger being fingerprinted, the larger the groove 102 of the selected prism 20A-20D. Dimension D1 of prism 20A will of course also have to increase for prisms 20A-20D with larger grooves 102 (dimension D8).

In the embodiment of prism 20A shown in FIGS. 6-11, image propagation surface 106 and light-receiving surface 104 are both curved so as to function as lenses. Light-receiving surface 104 forms a cylindrical lens and has a radius of curvature defined by dimension D9. This radius of curvature (dimension D9) is centered about a point of dimension D½ from side surfaces 112, and spaced from back surface 110 by a distance of dimension D10. In the embodiment of prism 20A described above, dimension D9 is 1.88 inches while dimension D10 is 0.25 inches. The radius of curvature or dimension D9 of lensed light-receiving surface 104 is therefore perpendicular to back surface 110 and parallel to bottom surface 108. Alternatively, light-receiving surface 104 can be characterized as being cylindrically curved about an imaginary vertical axis 105 which is perpendicular to bottom surface 108 and parallel to back surface 110.

Image propagation surface 106 is formed as a spherical convex lens in the embodiment shown, and has a radius of curvature of dimension D11 in both horizontal (X) and vertical (Y) directions. In the embodiment of prism 20A illustrated in FIGS. 6-11, radius of curvature or dimension D11 is centered at a distance of dimension D3 from bottom surface 108, halfway about back surface 110 ($d\frac{1}{2}$) and a distance of dimension D10 from back surface 110. In the embodiment described above, dimension D11 is 2.00 inches.

To increase the contrast of fingerprint images provided by or propagated from prism 20A, various surfaces are coated by an opaque substance to inhibit transmission of light. In the embodiment shown, bottom surface 108, back surface 110, and planar portions of upper surface 100 other than those of groove 102 are coated with an opaque substance. In addition, portions of side surfaces 112 adjacent back surface 110 (those portions at which mirror blocks 40 or 42 meet prisms 20A-20D as shown in FIG. 2) are also coated. Black paint can be applied to the above-identified surfaces to prevent transmission of light through absorption.

The optical properties of prism 20A (which are similar to those of prisms 20A-20D) are described with reference to FIGS. 12-14. Prism 20A is designed to utilize the optical principal of frustration of total internal reflection. Due to the relative indexes of refraction of air and the material of which the prism 20A is constructed, and the angles of upper surface 100 and surfaces 116 and 118 of groove 102 with respect to image propagation surface 106 and light-receiving surface 104, all light incident upon groove 102 when a finger is not present thereon is refracted downward toward bottom surface 108 or sideways toward side surfaces 112 upon its entry into prism 20A as illustrated in FIG. 12. Most importantly, virtually none of the light entering groove 102 will be directed out of image propagation surface 106. Virtually all of the light which strikes bottom surface 108 or the opaque portions of side surfaces 112 is absorbed due to the opaque coating, and not re-
reflected.

Light from lamp 53 will enter prism 20A through light receiving surface 104, image propagation surface 106, and portions of side faces 112 which are not coated with opaque material. Light so entering which impinges upon groove 102 will either pass through the groove and exit prism 20A, or be internally reflected to one of the opaque surfaces such as bottom surface 108 or back surface 110, and absorbed. Virtually none of the light incident upon prism 20A from lamp 53 will exit image propagation surface 106. As a result, an observer looking into image propagation surface 106 will see only "black" when no finger is positioned on surfaces 116 or 118 of groove 102.

Characteristics of a finger 132 are described with reference to FIG. 15 for use throughout subsequent portions of this specification. As shown, the tip of finger 132 has a finger pad or base area which has a fingerprint 134 thereon. Fingerprint 134 is a pattern formed by ridges 136 (light areas) and valleys 138 (dark areas) of the finger pad.

Referring back to FIGS. 13 and 14, when finger 132 is positioned within groove 102, the total internal reflection properties of prism 20A are frustrated or destroyed at points at which ridges 136 of the fingerpad contact surfaces 116 and 118 of groove 102. As shown in detail in FIG. 14, portions of prism 20A at which ridges 136 contact a surface such as 116 of groove 102 are charac-

terized by a skin-prism material boundary, while those portions at which valleys 138 are adjacent surface 116 are characterized by an air-prism material boundary as if a finger were never positioned in groove 102. At the areas at which ridges 136 contact surfaces 116 or 118 of groove 102, light which passes through the groove and into the skin will be partially absorbed by the skin and partially re-reflected back into prism 20A. Due to the different index of refraction of skin from that of air, this light which re-enters prism 20A at a skin-prism material boundary is refracted toward image propagation surface 106 and propagated therethrough. However, light which re-enters groove 102 at areas at which valleys 138 are adjacent surfaces 116 and 118 behaves as previously described due to the air-prism material interface between groove 102 and finger 132. When this light re-enters prism 20A, it is refracted downward and absorbed as previously described. These properties are illustrated graphically in FIG. 13. As a result, a visual image of fingerprint 134 (fingerprint image) is propagated through image propagation surface 106. This fingerprint image has "light" areas corresponding to ridges 136 of the fingerprint 134, and "dark" areas corresponding to valleys 138.

The fingerprint image of finger 132 propagated from prism 20A will be distorted from that of a planar "rolled" fingerprint image of the same finger. These distortions are broadly characterized as curvature errors, and size or scale errors, and are caused by different characteristics of finger 132, prism 20A, and their interaction.

As illustrated in FIG. 15, fingers such as 132 can be characterized by an imaginary longitudinal axis 139 which extends along the finger. The fingerpad on which fingerprint 134 is located is a compound curved surface in that it has base curvature about both an X-base curve axis 140 (generally referred to as an X-axis) and a Y-base curve axis 141 (generally referred to as a Y-axis). X-base curve axis 140 is oriented in a circumferential direction about longitudinal axis 139, and is formed by a locus of points which are perpendicular to a given point about the longitudinal axis.

Portions of fingerprint 134 about an X-base curve axis such as 140 would be colinear in a rolled fingerprint of fingerprint 134. However, the fingerprint image of fingerprint 134 propagated from image propagation surface 106 of prism 20A is planar, with an imaginary axis 142 which is perpendicular to the image plane (i.e., a plane "parallel" to image propagation surface 106) forming an observation angle OA with respect to longitudinal axis 139 of finger 132. Observation angle OA will be equal to angle A1 (FIG. 7) for those portions of the fingerprint image corresponding to portions of finger 132 which are positioned on fingerbody portion 113 of groove 102. Observation angle OA increases in accordance with the upwardly curved bottom wall 116 for those portions of the fingerprint image corresponding to portions of finger 132 which are positioned on fingertip portion 114 of groove 102. As a result of finger 132 being imaged at an observation angle OA which is between zero and ninety degrees and the curved nature of fingerprint 134 about X-base curve axis 140, portions of fingerprint 134 along an X-base curve axis such as 140 will appear as being curved upward in the fingerprint image, as opposed to being colinear if imaged at an observation angle OA of ninety degrees.

A graphic representation of these curvature errors inherently produced by prism 20A is illustrated in FIG.

32 where an image of a line 254 is curved about an X-base curve axis such as 140 and positioned in groove 102. Although in theory the amount of curvature error changes for portions of fingerprint 134 at different X-base curve axes such as 140 along Y-base curve axis 141, in practice the amount of curvature error variation over the relatively small part of finger 132 which is imaged is small. Curvature errors at all points of fingerprint 134 along Y-axis 141 are therefore essentially equal.

Scale errors are also caused by the fact that fingerprint 134 is on a compound curved surface of finger 132, and is imaged at an observation angle OA other than ninety degrees with respect to longitudinal axis 139. As a result of being imaged at an observation angle OA, true distances of portions of fingerprint 134 along a given Y-base curve axis such as 141 will be distorted. For example, in the fingerprint image, two ridges 136 which are actually separated about Y-base curve axis 141 on the finger by a given amount will appear to be compressed and separated by a distance less than the given amount. Furthermore, this Y-axis scale error is not constant about Y-base curve axis 141 since observation angle OA increases as bottom surface 116 in fingertip portion 114 of groove 102 curves upward toward surface 100 in the direction of image propagation surface 106.

For similar reasons, X-axis scale errors are inherent in portions of the fingerprint image which represent portions of the fingerprint about an X-base curve axis such as 140. These X-axis scale errors are also nonlinear due to curvature of fingerprint 134 along its X-base curve axis 140. For example, portions of fingerprint 134 at its center (i.e., opposite the fingernail), and portions on its side, which are separated by a given distance along X-base curve axis 140 will appear to be separated by different distances in the fingerprint image. Distances on the side of finger 132 will be compressed with respect to those in the center of the fingerprint.

The curved or lensed nature of image propagation surface 106 of prism 20A magnifies the fingerprint image of fingerprint 134 before it is propagated therefrom. Since groove 102 is actually an elongated and compound curved surface, different portions of the groove, and therefore different portions of fingerprint 134 when finger 132 is placed within the groove, will be at different distances from image propagation surface 106. This factor coupled with well known geometric optic principles results in different portions of fingerprint 134 being magnified to different degrees or amounts. Portions of fingerprint 134 near tip 145 of finger 132 will be nearest surface 106 and magnified the least amount. Portions of fingerprint 134 near back 143 of finger 132 will be positioned furthest from surface 106 and magnified the most. Portions of fingerprint 134 near sides 144 (only one side is visible in FIG. 15) will be magnified by an amount between the amount of those portions at back 143 and tip 145.

The result of these different amounts of magnification is to partially correct for curvature and scale errors described above. Curvature and scale errors in the fingerprint image which correspond to portions of fingerprint 134 at sides 144 of finger 132 are reduced due to the magnification (i.e., the inherent compression is expanded). Scale errors in the fingerprint image which correspond to portions of fingerprint 134 at back 143 of finger 132 are also reduced for similar reasons. In general, the magnification properties of image propagation

surface 106 of prism 20A have been found to reduce the curvature and scale errors in the fingerprint image.

Slap Print Prism

A first embodiment of slap print prism 18 is illustrated in FIGS. 16 and 17. Like individual finger prism 20A, slap print prism 18 has a first or finger-receiving surface 150, a second or light-receiving surface 154, a third or image propagation surface 156, a fourth or bottom surface 158, back surface 160, and side surfaces 162. Bottom surface 158 has a depth of dimension D20, and a width of dimension D21. Light-receiving surface 154 and back surface 160 are perpendicular to and have a height of dimensions D22 and D23, respectively, from bottom surface 158. Finger receiving surface 150 is planar, and forms an angle A5 with respect to bottom surface 158. Image propagation surface 156 is curved to function as a cylindrical lens, and has a radius of curvature of dimension D24 centered about a point at a distance of dimension D25 above the intersection of finger-receiving surface 150 and back surface 160, and a distance of dimension D26 toward light-receiving surface 154 from back surface 160. Image propagation surface 156 can therefore be characterized as a cylindrical lens having a radius of curvature about an imaginary horizontal axis 151 which is parallel to both back surface 160 and bottom surface 158. Dimension D21 of slap print prism 18 must be sufficient so as to enable a plurality of fingers (e.g., four fingers of a hand less the thumb) to be positioned on finger-receiving surface 150. In one preferred embodiment, dimension D21 is five inches. In the same embodiment, dimension D20 is 1.75 inches, dimension D22 is 1.38 inches, dimension D23 is 1.25 inches, dimension D24 is 1.00 inches, dimension D25 is 0.75, and dimension D26 is 0.88 inches.

Slap print prism 18 utilizes and operates on the same optical principles as that of individual fingerprint prism 20A described above. Bottom surface 158, side surfaces 162, and back surface 160 are coated with black paint so as to make these surfaces opaque. Slap print images of the four fingers of a hand, excluding the thumb, which are positioned on finger-receiving surface 150 will be propagated through image propagation surface 156. Valleys 138 of a finger such as 132 (FIG. 15) will be "dark" in the image, while ridges 136 will be light. The curved nature of image propagation surface 156 causes this surface to function as a lens, and magnifies the image in a direction corresponding to that along the longitudinal axis (i.e., Y-base curve axis) of the finger. This magnification partially corrects for scale errors along Y-base curve axis 141 (FIG. 15) due to the observation angle OA at which fingerprint 134 is imaged. Since finger-receiving surface 150 is planar, fingerprint 134 of a finger such as 132 is forced into a planar orientation when positioned on surface 150. As a result, X-axis curvature and scale errors in fingerprint images provided by slap print lens 18 are negligible compared to those of images provided by finger prisms such as 20A.

A second or alternative embodiment of the slap print prism, that being slap print prism 18', is illustrated in FIGS. 3A, 3B, 18 and 19. Slap print lens 18' is identical to slap print lens 18 previously described in all respects except for image propagation surface 156' which is coplanar with light-receiving surface 162. Image propagation surface 156' does not, therefore, magnify fingerprint images of fingers such as 132 positioned on finger-receiving surface 150. As a result, Y-axis scaling errors

are not partially corrected. Slap print lens 18' functions in all other regards exactly like that of slap print lens 18 previously described.

Processor Subsystem

Processor subsystem 30 and its interrelationship to video camera 28, video monitor 14, printer 16, data terminal 6, LEDs 316A-316E and 318A-318E of display 13, LEDs 21A-21D of key pad 19, motor 76 and microswitches 87 and 89 is best described with reference to FIG. 20. As shown, processor subsystem 30 includes programmable computing means such as computer 200, random access memory or RAM 202, read only memory or ROM 204, and frame digitizer 206.

Fingerprint images from optics subsystem 22 are imaged by camera 28 through its objective lens. In response, camera 28 generates video signals which are representative of the fingerprint image. The video signals are then distributed to both video monitor 14 and frame digitizer 206. Video monitor 14 (which will typically be interfaced to microprocessor 200 through a video driver which is not shown) can thereby provide a real-time display of the fingerprint image being imaged by camera 28. In one preferred embodiment, camera 28 and monitor 14 are commercially available devices which utilize a standard raster and standard frame rates. Computer 200 is preferably a commercially available 32-bit microprocessor.

When an operator of fingerprinting system 10 observes on monitor 14 a fingerprint image they wish to "freeze" or record, key pad 19 will be appropriately actuated. In response, computer 200 will cause frame digitizer 206 to digitize the video signals of the frame being displayed on monitor 14, and provide digital image data characteristic of the "captured" fingerprint image to computer 200. The fingerprint image data is temporarily stored in RAM 202. Computer 200 then retrieves the fingerprint image data and processes it in accordance with image enhancement software programs which can be stored in ROM 204. Computer 200 thereby generates enhanced fingerprint image data. In response to operator control through data terminal 6, computer 200 can retrieve the enhanced image data from RAM 202 and provide it to video monitor 14. The enhanced fingerprint image can thereby be visually displayed. Alternatively, the operator can cause the enhanced image data to be propagated to printer 16 which will print the enhanced fingerprint image. Printer 16 is preferably a high resolution laser printer.

Frame digitizer 206 provides the digital image data in the form of an array of pixel values representative of the intensity of the fingerprint image at corresponding discrete or pixel locations. An image array IA of pixel values $PV_{n,m}$ is illustrated in FIG. 21. Image array IA is formed of N rows and M columns of pixel values $PV_{n,m}$. In one embodiment, image array IA is formed of N equal to four hundred and eighty rows and M equal to five hundred and twelve columns of pixel values $PV_{n,m}$. Pixel values $PV_{n,m}$ are digital values representative of the intensity of the fingerprint image at corresponding pixel locations $PL_{n,m}$ of image array IA. In one embodiment frame digitizer 206 includes an eight-bit analog-to-digital converter which converts the video signals to eight-bit pixel values $PV_{n,m}$ characteristic of image intensity at corresponding pixel locations $PL_{n,m}$. In this embodiment, an eight-bit pixel value $PV_{n,m}$ representative of a decimal zero (i.e. "00000000") is a minimum pixel value PV_{MIN} and

characterizes a lowest intensity or darkest pixel location $PL_{n,m}$. A pixel value representative of a decimal two hundred and fifty-six (i.e., "11111111") is a maximum pixel value PV_{MAX} and represents a highest intensity or whitest pixel location. A pixel value $PV_{n,m}$ representative of a digital 128 (i.e., "10101010") represents a pixel location $PL_{n,m}$ having an intensity half-way between the lowest and highest intensities (i.e., grey).

Having been generated by frame digitizer 206, pixel values $PV_{n,m}$ of image array IA will be stored within RAM 202 at indexed locations corresponding to pixel locations $PL_{n,m}$. Computer 200 will then retrieve image array pixel values $PV_{n,m}$ and process them in accordance with a Noise Average software algorithm stored in ROM 204 to produce a noise averaged array NAA of pixel values $PV_{n,m}$ (FIG. 22). Noise averaged pixel values $PV_{n,m}$ are then temporarily stored within RAM 202 prior to implementation of subsequent image processing software algorithms. Following this approach, computer 200 generates an illumination equalized array IEA of illumination equalized pixel values $PV_{n,m}$ in accordance with an Illumination Equalize algorithm, a directional filtered array DFA of directional filtered pixel values $PV_{n,m}$ in accordance with a Directional Filter algorithm, and an unhaired array UA of unhaired (artifact removed) pixel values $PV_{n,m}$ in accordance with an Unhair algorithm. Unhaired pixel values $PV_{n,m}$ are then translated in position in accordance with a Curvature Correction algorithm to generate a curvature corrected array CCA of curvature corrected pixel values $PV_{n,m}$. Curvature corrected pixel values $PV_{n,m}$ are then scaled or translated in position, first vertically to produce a vertically scaled array VA of vertically scaled pixel values $PV_{n,m}$, and then horizontally to produce a horizontally scaled array HA of horizontally scaled pixel values $PV_{n,m}$. This processing is done in accordance with Vertical Scaling and Horizontal Scaling algorithms, respectively. Finally, the horizontally scaled array HA of pixel values $PV_{n,m}$ is thresholded to produce a threshold array of thresholded values $PV_{n,m}$ characteristic of the enhanced fingerprint image. The thresholded array of pixel values are then stored in RAM 202, and can be utilized by printer 16 to produce a printed record of the fingerprint image.

A. Noise Average

To initiate image processing, computer 200 will retrieve pixel values $PV_{n,m}$ of image array IA (FIG. 21) from RAM 202, and process these pixel values in accordance with a Noise Average program stored within ROM 204. As a result of this processing, computer 200 generates a noise averaged array NAA of noise averaged pixel values $PV_{n,m}$ as illustrated in FIG. 22. The Noise Average program removes random variations, or noise, in imaged pixel values $PV_{n,m}$ which can be introduced for various reasons such as electronic or electromagnetic noise.

Each noise averaged pixel value $PV_{n,m}$ at pixel locations $PL_{n,m}$ of noise averaged array NAA is computed as a function of weighted average of the particular image pixel value $PV_{n,m}$ at the same pixel location $PL_{n,m}$ of image array IA, and a plurality of image pixel values $PV_{n,m}$ at pixel locations $PL_{n,m}$ surrounding or in the area of the particular pixel value $PV_{n,m}$ being noise averaged. In a preferred embodiment described below, noise averaged pixel values $PV_{n,m}$ are computed as a function of a weighted average of a given

image pixel value PV_{n,m_I} , and pixel values PV_{n,m_I} at pixel locations $PL_{n,m}$ of image array IA immediately adjacent to the given pixel value. A formula for computing noise averaged pixel values PV_{n,m_N} in accordance with a preferred weighted average function is described by Equation 1 below. Other weighted average functions can of course also be used.

$$PV_{n,m_N} = [4PV_{n,m_I} + 2(PV_{n-1,m_I} + PV_{n,m+1_I} + PV_{n+1,m_I} + PV_{n,m-1_I}) + PV_{n-1,m-1_I} + PV_{n-1,m+1_I} + PV_{n+1,m+1_I} + PV_{n+1,m-1_I}]/16 \quad \text{Eq. 1}$$

The weighted average function of Equation 1 assigns the center pixel value PV_{n,m_I} (the particular pixel value to be noise averaged) a weight of four, adjacent side pixel values a weight of two, and adjacent corner pixel values a weight of one. Equation 2 below describes as an example the application of Equation 1 to a particular image pixel value $PV_{2,2_I}$ to be noise averaged.

$$PV_{2,2_N} = [4PV_{2,2_I} + 2(PV_{1,2_I} + PV_{2,3_I} + PV_{3,2_I} + PV_{2,1_I}) + PV_{1,1_I} + PV_{1,3_I} + PV_{3,3_I} + PV_{3,1_I}]/16. \quad \text{Eq. 2}$$

It is evident that the weighted average function described by Equation 1 is not applicable to pixel values PV_{n,m_I} at pixel locations $PL_{n,m}$ at the edge of image array IA (i.e., pixel values PV_{n,m_I} for $n=1$ and $1 \leq m \leq M$, for $1 \leq n \leq N$ and $m=1$, for $n=N$ and $1 \leq m \leq M$, for $1 \leq n \leq N$ and $m=M$). The reason is that there are no "adjacent" pixel values beyond the edge of image array IA. In one embodiment these "edge" pixel values are ignored by the Noise Average program since they likely represent unimportant portions of the fingerprint image anyway. The noise averaged pixel values PV_{n,m_N} at these edges are simply set equal to their corresponding pixel values PV_{n,m_I} in the image array, as described by Equation 3.

$$PV_{n,m_N} = PV_{n,m_I} \text{ for: } \begin{array}{l} n = 1, 1 \leq m \leq M; \\ 1 \leq n \leq N, m = 1; \\ n = N, 1 \leq m \leq M; \text{ and} \\ 1 \leq n \leq N, m = M \end{array} \quad \text{Eq. 3}$$

Having generated a noise averaged array NA of pixel values PV_{n,m_N} in accordance with the above-described approach, computer 200 will store the noise averaged pixel values at indexed locations within RAM 202 for subsequent processing.

B. Illumination Equalize

In practice, the manner in which slap print prism 18' and finger prisms 20A-20D are illuminated by lamps 31 and 53, respectively, results in varying amounts of light being propagated by the prisms to different portions of a fingerprint such as 134 (FIG. 15) being imaged. As a result, the illumination intensity level over each fingerprint image imaged by camera 28 will vary. However, it is desirable that the fingerprint be illuminated with a constant intensity throughout. This is effectively performed by computer 200 which processes pixel values PV_{n,m_N} of noise averaged array NAA in accordance with an illumination Equalize program stored in ROM 204, and generates an illumination equalized array IEA

of illumination equalized pixel values PV_{n,m_E} illustrated in FIG. 23.

The generation of illumination equalized pixel values PV_{n,m_E} from noise averaged pixel values PV_{n,m_N} is described with reference to FIG. 24. For a particular pixel value PV_{n,m_N} at a particular pixel location $PL_{n,m}$ that it is desired to illumination equalize, computer 200 first selects a subarray SA of pixel values which includes the pixel value to be illumination equalized. Although subarray SA has been chosen as a three-by-three subarray with the particular pixel value PV_{n,m_N} to be equalized in the center thereof for purposes of example in FIG. 24, subarrays of a larger size are preferred and can produce better results. In one embodiment, computer 200 selects an eight-by-eight subarray of pixel values surrounding the pixel value to be illumination equalized. However, the algorithm is fully described with the three-by-three subarray SA illustrated in FIG. 24.

Having selected a subarray $SA_{n,m}$, for the particular pixel value PV_{n,m_N} to be equalized, computer 200 will sum all pixel values PV_{n,m_N} within the subarray, and divide by the number of pixel values summed, to generate a subarray average value $SAV_{n,m}$. Equation 4 below mathematically describes this procedure for the general three-by-three subarray $SA_{n,m}$ illustrated in FIG. 24.

$$SAV_{n,m} = [PV_{n-1,m-1_N} + PV_{n-1,m_N} + PV_{n-1,m+1_N} + PV_{n,m-1_N} + PV_{n,m_N} + PV_{n,m+1_N} + PV_{n+1,m-1_N} + PV_{n+1,m_N} + PV_{n+1,m+1_N}]/9 \quad \text{Eq. 4}$$

Computer 200 then computes the illumination equalized pixel value PV_{n,m_E} as a function of the particular noise averaged pixel value PV_{n,m_N} to be illumination equalized, the subarray average value $SAV_{n,m}$ for the particular pixel value to be illumination equalized, and a constant K characteristic of an average illumination expected of pixel values of the image. Constant K (which can be stored in RAM 202 or ROM 204) is a threshold value and can be set as a function of noise in the fingerprint image. In one embodiment, constant K is representative of a pixel value $PV_{n,m}$ having an intensity halfway between the lowest and highest intensities which can be displayed on monitor 14 (e.g., $K = (PV_{MAX} - PV_{MIN})/2$). Following the above example which utilizes an eight-bit analog-to-digital converter in frame digitizer 206, K would equal one hundred and twenty-eight.

In the course of carrying out these computations, computer 200 first generates a pixel difference value $PDV_{n,m}$ representative of the difference between the particular pixel value PV_{n,m_N} to be illumination equalized, and the subarray average value $SAV_{n,m}$ of the subarray of which it is an element. This operation is mathematically described by Equation 5.

$$PDV_{n,m} = PV_{n,m_N} - SAV_{n,m} \quad \text{Eq. 5}$$

Constant K is then added to pixel difference values $PDV_{n,m}$ to generate an intermediate illumination equalized pixel value $IEPV_{n,m}$ as described by Equation 6 below.

$$IEPV_{n,m} = PDV_{n,m} + K \quad \text{Eq. 6}$$

The illumination equalized pixel value $PV_{n,mE}$ is finally computed as a function of its corresponding intermediate illumination equalized pixel value $IEPV_{n,m}$. If the intermediate illumination equalized pixel value $IEPV_{n,m}$ is less than the minimum pixel value PV_{MIN} or greater than the maximum pixel value PV_{MAX} , the illumination equalized pixel value $PV_{n,mE}$ is unconditionally set to PV_{MIN} or PV_{MAX} , respectively. The illumination equalized pixel value $PV_{n,mE}$ is set to the intermediate illumination equalized pixel value $IEPV_{n,m}$ if $IEPV_{n,m}$ is greater than or equal to the minimum pixel value PV_{MIN} , and less than or equal to the maximum pixel value PV_{MAX} . These relationships are mathematically described by Equations 7-9 below.

$$PV_{n,mE} = PV_{MIN} \text{ if } IEPV_{n,m} < PV_{MIN}. \quad \text{Eq. 7}$$

$$PV_{n,mE} = IEPV_{n,m} \text{ if } PV_{MIN} \leq IEPV_{n,m} \leq PV_{MAX}. \quad \text{Eq. 8}$$

$$PV_{n,mE} = PV_{MAX} \text{ if } IEPV_{n,m} > PV_{MAX}. \quad \text{Eq. 9}$$

The procedures described above, including the selection of a subarray and the mathematical operations described by Equations 4-9, are carried out by computer 200 to generate an illumination equalized pixel value $PV_{n,mE}$ for each noise averaged pixel value $PV_{n,mN}$ to be illumination equalized. However, since subarrays SA are selected in such a manner that the pixel value $PV_{n,mN}$ to be illumination equalized is at or near its center, it is evident that this procedure cannot be used to illumination equalize pixel values $PV_{n,mN}$ near edges of noise averaged array NAA. For example, using the three-by-three subarray SA illustrated in FIG. 24, it will not be possible to illumination equalize the pixel values $PV_{n,mN}$ of the outermost rows and columns of noise averaged array NAA. Since these edge pixel values $PV_{n,mN}$ will likely represent unimportant parts of the fingerprint image, they are simply set equal to their noise averaged pixel values as described by Equation 10. A similar procedure is followed when using a subarray SA of larger size.

$$PV_{n,mE} = PV_{n,mN} \text{ for: } \begin{aligned} n = 1, 1 \leq m \leq M; \\ 1 \leq n \leq N, m = 1; \\ n = N, 1 \leq m \leq M; \text{ and} \\ 1 \leq n \leq N, m = M. \end{aligned} \quad \text{Eq. 10}$$

Following the above-described procedure, an entire illumination equalized array IEA of pixel values $PV_{n,mE}$ can be generated by computer 200. Computer 200 will store illumination equalized pixel values $PV_{n,mE}$ in RAM 202 for subsequent processing.

C. Directional Filter

The fingerprint image characterized by illumination equalized array IEA is formed by pixel values $PV_{n,mE}$ which represent relatively light curves characteristic of fingerprint ridges 136 (FIG. 15), and pixel values which represent relatively dark curves characteristic of fingerprint valleys 138. To enhance the fingerprint image represented by illumination equalized array IEA, it has been found advantageous to filter pixel values $PV_{n,mE}$ in such a way as to emphasize the directional aspects of portions of the array representing fingerprint ridges 136 and valleys 138. This directional filtering is performed by computer 200 in accordance with a Directional Fil-

ter program stored within ROM 204. The result is a directional filtered array DFA of directional filtered pixel values $PV_{n,mD}$ as illustrated in FIG. 25.

Generally stated, the Directional Filtering program is implemented by computer 200 in a multiple-step manner. First, for each particular pixel value $PV_{n,mE}$ for $1 < n < N$, $1 \leq m < M$ of illumination equalized array IEA (i.e., for all pixel values $PV_{n,mE}$ other than those in the top and bottom rows and rightmost column) computer 200 computes an absolute value of the difference between that particular pixel value and a horizontally adjacent pixel value (HorizDif), a vertically adjacent pixel value (VertDif), an adjacent pixel value at a positive slope (PosDif) and an adjacent pixel value at a negative slope (NegDif). This procedure is described generally by Equations 11-14 below.

$$\text{HorizDif}_{n,m} = |PV_{n,mE} - PV_{n,m+lE}| \quad \text{Eq. 11}$$

$$\text{VertDif}_{n,m} = |PV_{n,mE} - PV_{n+l,mE}| \quad \text{Eq. 12}$$

$$\text{PosDif}_{n,m} = |PV_{n,mE} - PV_{n-l,m+lE}| \quad \text{Eq. 13}$$

$$\text{NegDif}_{n,m} = |PV_{n,mE} - PV_{n+l,m+lE}| \quad \text{Eq. 14}$$

Horizontal difference values HorizDif_{n,m}, vertical difference values VertDif_{n,m}, positive difference values PosDif_{n,m} and negative difference values NegDif_{n,m} for pixel values $PV_{n,mE}$ for each $1 < n < N$ and $1 \leq m < M$ are stored at indexed locations within RAM 202.

As illustrated graphically in FIG. 26, computer 200 next divides illumination equalized array IEA into a plurality of regular subarrays 230A-230Y (illustrated with solid lines) and offset subarrays 232A-232JJ (illustrated with broken lines). Offset subarrays 232A-232JJ are offset both horizontally and vertically with respect to regular subarrays 230A-230Y in the embodiment shown. All pixel values $PV_{n,mE}$ of illumination equalized array IEA will be located within both one of regular subarrays 230A-230Y and one of offset subarrays 232A-232JJ. Subarrays 230A-230Y and 232A-232JJ are sized so as to have more pixel values $PV_{n,mE}$ on a side than an expected width of a fingerprint ridge 136 (FIG. 15) or valley 138 as represented by the pixel values of the subarray. In one embodiment, computer 200 causes subarrays 230A-230Y and 232A-232JJ to be rectangular with 32 pixel values $PV_{n,mE}$ per side when processing an image from a finger prism such as 20A.

Computer 200 next determines a "dominant direction" of the portion of the fingerprint image represented by pixel values $PV_{n,mE}$ of each regular subarray 230A-230Y and each offset subarray 232A-232JJ. This is done as a function of the difference values HorizDif_{n,m}, VertDif_{n,m}, PosDif_{n,m}, and NegDif_{n,m} computed for the pixel values $PV_{n,mE}$ within that particular subarray 230A-230Y and 232A-232JJ. This is done by computing, for each subarray 230A-230Y and 232A-232JJ, a sum HDSum, VDSum, PDSum, and NDSum of the difference values HorizDif_{n,m}, VertDif_{n,m}, PosDif_{n,m}, and NegDif_{n,m}, respectively, which were previously computed for pixel values $PV_{n,mE}$ within that subarray. This procedure is mathematically described by Equations 15-22.

$$\text{HDSum}_{230xx} = \sum \text{HorizDif}_{n,m} \quad \text{Eq. 15} \quad (\text{For all } PV_{n,mE} \text{ of subarray } 230xx \text{ for}$$

$$\text{VDSum}_{230xx} = \sum \text{VertDif}_{n,m} \quad \text{Eq. 16}$$

-continued

$PDSum_{230xx} = \Sigma PosDifn,m$	Eq. 17	which difference values
$NDSum_{230xx} = \Sigma NegDifn,m$	Eq. 18	were computed)
$HDSum_{232xx} = \Sigma HorizDifn,m$	Eq. 19	(For all $PV_{n,mE}$ of
$VDSum_{232xx} = \Sigma VertDifn,m$	Eq. 20	subarray 232xx for
$PDSum_{232xx} = \Sigma PosDifn,m$	Eq. 21	which difference values
$NDSum_{232xx} = \Sigma NegDifn,m$	Eq. 22	were computed)

An understanding of the operations described by Equations 15-22 is facilitated by FIG. 27, in which regular subarrays 230A-230Y and offset subarrays 232A-232JJ are sized to have four pixel values $PV_{n,mE}$ per side for purposes of example. It will be understood that for most subarrays 230A-230Y and 232A-232JJ (those which do not include pixel values $PV_{n,mE}$ in the top or bottom rows or rightmost column), difference values HorizDifn,m, VertDifn,m, PosDifn,m, and NegDifn,m for all pixel values $PV_{n,mE}$ within the subarray will have been computed and will be summed. However, for those subarrays which have pixel values $PV_{n,mE}$ in the top or bottom rows or rightmost column of illumination equalized array IEA, not all of the pixel values therein will have had difference values HorizDifn,m, VertDifn,m, PosDifn,m, and NegDifn,m, computed therefor. As a result, only those pixel values $PV_{n,mE}$ for which difference values were computed can be summed to contribute to difference value sums HDSum, VDSum, PDSum and NDSum of subarrays 230A-230Y and 232A-232JJ. As an example, for offset subarray 232A in FIG. 27, only pixel value $PV_{2,2E}$ had difference values computed therefor.

Following the above description, $HDSum_{232A} = -HorizDif_{2,2}$, $VDSum_{232A} = -VertDif_{2,2}$, $PDSum_{232A} = -PosDif_{2,2}$, and $NDSum_{232A} = -NegDif_{2,2}$. Also by way of example, for regular array 230A, $HDSum_{230A} = -$

$VDSum_{230xx}$, $PDSum_{230xx}$ or $NDSum_{230xx}$ of that subarray 230xx. Similarly, the dominant direction of an offset subarray 232xx is the direction associated with the lesser of $HDSum_{232xx}$, $VDSum_{232xx}$, $PDSum_{232xx}$, or $NDSum_{232xx}$. In those cases in which more than one of the difference value sums are equal, the dominant direction is that direction which is 90° offset from the direction characterized by the greatest difference value sum.

Having determined the dominant directions, computer 200 performs a directional filter of each pixel value $PV_{n,mE}$ of image array IEA as a function of a weighted average of the particular pixel value and adjacent pixel values in the dominant direction the subarrays 230A-230Y, 232A-232JJ of which the particular pixel value is an element.

A preferred embodiment of this directional filtering is best described as follows. First, each pixel value $PV_{n,mE}$ is directional filtered as a function of the dominant direction of the regular subarray 230A-230Y of which it is a member to provide a regular subarray directional filtered pixel value $RSPV_{n,mE}$. Second, each pixel value is directional filtered as a function of the dominant direction of the offset subarray 232A-232JJ to provide an offset subarray directional filtered pixel value $OSPV_{n,mE}$ of which it is a member. Finally, the regular subarray directional filtered pixel value $RSPV_{n,mE}$ and offset subarray directional filtered pixel value $OSPV_{n,mE}$ are averaged to generate the corresponding directional filtered pixel value $PV_{n,mD}$ of directional filtered array DFA.

Preferred weighted average formulas for generating regular subarray directional filtered pixel values $RSPV_{n,mE}$ for a particular pixel value $PV_{n,mE}$ are described by equations 23-26.

$$RSPV_{n,mE} = (2 PV_{n,mE} + PV_{n,m} - 1_E + PV_{n,m} + 1_E)/4 \quad \text{Eq. 23}$$

(when the dominant direction of the regular subarray is horizontal)

$$RSPV_{n,mE} = (2 PV_{n,mE} + PV_{n-1,mE} + PV_{n+1,mE})/4 \quad \text{Eq. 24}$$

(when the dominant direction of the regular subarray is vertical).

$$RSPV_{n,mE} = (2PV_{n,mE} + PV_{n-1,m} + 1_E + PV_{n+1,m} - 1_E)/4 \quad \text{Eq. 25}$$

(when the dominant direction of the regular subarray is positive slope).

$$RSPV_{n,mE} = (2PV_{n,mE} + PV_{n-1,m} - 1_E + PV_{n+1,m} + 1_E)/4 \quad \text{Eq. 26}$$

(when the dominant direction of the regular subarray is negative slope).

Offset subarray directional filtered pixel values $OSPV_{n,mE}$ can be computed in a similar manner using equations 27-30.

$$OSPV_{n,mE} = (2PV_{n,mE} + PV_{n,m} - 1_E + PV_{n,m} + 1_E)/4 \quad \text{Eq. 27}$$

(if the dominant direction of the offset subarray is horizontal).

$$OSPV_{n,mE} = (2PV_{n,mE} + PV_{n-1,mE} + PV_{n+1,mE})/4 \quad \text{Eq. 28}$$

(if the dominant direction of the offset subarray is vertical).

$$OSPV_{n,mE} = (2PV_{n,mE} + PV_{n-1,m} + 1_E + PV_{n+1,m} - 1_E)/4 \quad \text{Eq. 29}$$

(if the dominant direction of the offset subarray is positive slope).

$$OSPV_{n,mE} = (2PV_{n,mE} + PV_{n-1,m} - 1_E + PV_{n+1,m} + 1_E)/4 \quad \text{Eq. 30}$$

(if the dominant direction of the offset subarray is negative slope).

$HorizDif_{2,2} + HorizDif_{2,3} + HorizDif_{2,4} + HorizDif_{3,2} + HorizDif_{3,3} + HorizDif_{3,4} + HorizDif_{4,2} + HorizDif_{4,3} + HorizDif_{4,4}$

Computer 200 next determines the dominant direction of each regular subarray 230A-230Y and offset subarray 232A-232JJ as a function of the difference value sums of that subarray. In particular, the dominant direction for a subarray 230xx is the direction or orientation associated with the lesser of $HDSum_{230xx}$,

Directional filtered pixel values $PV_{n,mD}$ are generated by computer 200 by averaging corresponding regular subarray pixel values $RSPV_{n,mE}$ and offset subarray pixel values $OSPV_{n,mE}$. The procedure is described mathematically by Equation 31.

$$PV_{n,mD} = (RSPV_{n,mE} + OSPV_{n,mE})/2 \quad \text{Eq. 31}$$

Following the above-described procedure, computer 200 can generate a directional filtered array DFA of directional filtered pixel values $PV_{n,mD}$ as illustrated in FIG. 25. For pixel values $PV_{n,mE}$ in the top and bottom rows and rightmost column of illumination equalized array IEA which are not directional filtered, computer 200 sets their corresponding directional filtered pixel value equal to their illumination equalized pixel value, as described by equation 32 below. This procedure will not materially affect the image represented by directional filtered array DFA since these pixel values are on the edges.

$$PV_{n,mD} = PV_{n,mE} \text{ for: } \begin{array}{l} n = 1, 1 \leq m < M \\ n = N, 1 \leq m < M \\ 1 \leq n \leq N, m = M \end{array} \quad \text{Eq. 32}$$

D. Unhair

The fingerprint image represented by directional filtered array DFA will typically include artifacts of "hairs" which are undesirable noise components of the image. Artifacts such as 240 are shown within fingerprint image 242 in FIG. 28. As is evident from FIG. 28, artifacts 240 typically are finer than or have a width which is less than either valleys 138 or ridges 136 of the fingerprint image. To enhance the image represented by directional filtered array DFA, computer 200 "unhairs" the image by processing this array in accordance with an Unhair program stored within ROM 204. The result is an artifact removed or unhaired array UA of unhaired pixel values $PV_{n,mU}$ illustrated in FIG. 29.

The Unhair program implemented by computer 200 operates on the assumption that artifacts 240 will have a width which is less than the width of either valleys 138 or ridges 136 of a fingerprint image such as 242 illustrated in FIG. 28 (as represented by directional filtered array DFA). It is therefore assumed that the width of valleys 138 and ridges 136 will occupy a minimum number of adjacent pixel locations $PL_{n,m}$ of directional filtered array DFA, while the width of an artifact 240 will occupy less than the number of adjacent pixel locations of a valley or ridge. A graphic representation of a portion of directional filtered array DFA illustrating a valley 138 and artifact 240 is illustrated in FIG. 30. It must be understood that the shading in FIG. 30 is merely for purposes of illustration, and is actual representative of the magnitude of pixel values $PV_{n,mD}$ at the corresponding pixel locations $PL_{n,m}$. In FIG. 30, artifact 240 is vertically oriented and has a width of two pixel locations $PL_{n,m}$, while valley 138 has a minimum width of five "occupied" pixel locations $PL_{n,m}$.

Data representative of the width of artifacts 240 that it is desired to remove, in terms of a number W of adjacent pixel locations $PL_{n,m}$ this width would occupy, is stored in RAM 202 or ROM 204. In one embodiment, it is assumed that a vertical "feature" of fingerprint image 242 which has a width less than W equals two pixel locations $PL_{n,m}$ is an artifact 240. Any vertically oriented features which are not more than W pixel locations $PL_{n,m}$ wide are deemed to be artifacts 240, and the pixel values $PV_{n,mD}$ representing these features are unconditionally set to a value of PV_{MAX} so as to eliminate these features from the image.

Following the Unhair program to eliminate vertically oriented artifacts 240, computer 200 processes groups of $W+2$ horizontally adjacent pixel values $PV_{n,mD}$ of

directional filtered array DFA, i.e., $PV_{n,m-1D}$, $PV_{n,mD}$, $PV_{n,m+1D}$, . . . $PV_{n,m+W_D}$. Each of these pixel values must be compared to an unhair threshold value UT to determine if it is representative of a dark portion image 242 (i.e., a valley 138 or artifact 240), or a light portion (i.e., a ridge 136). Pixel values $PV_{n,mD}$ which are less than threshold value UT are deemed to represent dark portions of image 242, while those greater than or equal to threshold value UT are deemed to represent light portions of the image. Threshold value UT can be stored in RAM 204, and be equal to $(PV_{MAX} - PV_{MIN})/2$.

Computer 200 first looks to a group of W horizontally adjacent pixel values $PV_{n,m}$ to $PV_{n,m+(W-1)}$. If each of these values is less than the threshold value UT , then they are known to represent a dark feature of image 242. If this feature is a fingerprint valley 138, then one of the pixel values $PV_{n,m}$ adjacent to this group (i.e., one of $PV_{n,m-1}$ or $PV_{n,m+W}$) will also be dark, i.e., less than threshold UT . If this is the case, then the corresponding unhaired pixel value $PV_{n,mU}$ is set to the value of its corresponding directional filtered pixel value $PV_{n,mD}$. This relationship is mathematically described by Equation 32a below.

If the group of W adjacent pixel values $PV_{n,m}$ to $PV_{n,m+(W-1)}$ are all less than the threshold UT but both adjacent pixel values $PV_{n,m-1}$ and $PV_{n,m+W}$ are greater than or equal to the threshold UT , the group of W adjacent pixel values represent an artifact, and computer 200 sets all pixel values $PV_{n,m-1U}$ to $PV_{n,m+W_U}$ equal to PV_{MAX} , thereby eliminating the artifact from the image. This relationship is mathematically described by Equation 32b and takes precedence over equation 32a. That is, a pixel value $PV_{n,mU}$ initially set in accordance with equation 32a can subsequently be set to PV_{MAX} in accordance with equation 32b.

Finally, computer 200 will set pixel values $PV_{n,mU}$ equal to the corresponding value $PV_{n,mD}$ in directional filtered array DFA if not all W adjacent pixels $PV_{n,m}$ to $PV_{n,m+(W-1)}$ of the group are less than threshold UT . This relationship is described mathematically by equation 32a. Once the above procedure has been implemented for all pixel values $PV_{n,m}$ for $1 \leq n \leq N$, $2 \leq m \leq M - W$, an unhaired array UA is generated. The Unhair program is not performed on edge pixel values $PV_{n,mD}$ for $1 < n < N$, $M - W < m \leq M$. For these pixel values, $PV_{n,mU}$ are set equal to $PV_{n,mD}$ in accordance with Equation 32c.

For each $PV_{n,m}$ for $1 \leq n \leq N$, $2 \leq m \leq M - W$. If $PV_{n,mD}$ and $PV_{n,m+1D}$. . . and $PV_{n,m+(W-1)D} < UT$ and: $PV_{n,m-1D}$ or $PV_{n,m+W_D} < UT$ or if any of $PV_{n,mD}$, $PV_{n,m+1D}$, . . . $PV_{n,m+(W-1)D} > UT$ then:

$$PV_{n,mU} = PV_{n,mD} \quad \text{Eq. 32a}$$

If $PV_{n,mD}$ and $PV_{n,m+1D}$, . . . and $PV_{n,m+(W-1)D} < UT$ and: $PV_{n,m-1D}$ and $PV_{n,m+W_D} \geq UT$ then:

$$PV_{n,m-1D}, PV_{n,mD}, \dots \text{ and } PV_{n,m+W_D} = PV_{MAX} \quad \text{Eq. 32b}$$

$$PV_{n,mU} = PV_{n,mD} \text{ for } 1 < n < N, M - W < m \leq M. \quad \text{Eq. 32c}$$

Horizontally oriented artifacts can be removed in a similar manner using groups of W vertically adjacent pixel values $PV_{n,mD}$. However, experience has shown most artifacts 240 to be vertically oriented.

E. Curvature Correction

As previously discussed, since finger prisms 20A-20D provide fingerprint images which are taken at an observation angle OA with respect to a longitudinal axis 139 of finger 132 (FIG. 15), those portions of the fingerprint which are positioned adjacent one another about an X -base curve axis 140 at any given point about the longitudinal axis and which would be linearly positioned with respect to one another in a rolled fingerprint image, will actually be projected in such a manner as to appear to be curved in an upwardly arced manner within un-haired array UA . Computer 200 processes pixel values $PV_{n,mU}$ of un-haired array UA in accordance with a Curvature Correction program to produce a curvature corrected array CCA (FIG. 31) of curvature corrected pixel values $PV_{n,mC}$ which characterize the fingerprint image in a curvature corrected manner. Basically, the Curvature Correction program causes un-haired pixel values $PV_{n,mU}$ to be translated vertically in position in accordance with tabulated curvature correction data characteristic of the curvature inherent in images provided by prisms 20A-20D.

Curvature correction data is generated by computer 200 through the use of a flexible template 250 as illustrated in FIG. 32. As shown, template 250 has a linear pattern of indicia 252 which can include a line 254 and hatch marks 256A-256G at known and preferably evenly spaced locations thereabout. Template 250 is shaped in such a manner as to correspond to the curvature of the finger, with line 254 oriented perpendicular to an imaginary axis 139 representing the longitudinal axis of finger 132. Line 254 will therefore be parallel to an X -base curve axis 140 of finger 132. Shaped template 250 is then positioned within groove 102 of prism 20A with pattern of indicia 252 oriented in the above-identified manner. As a result of the optical transfer function of prism 20A, the image of line 254 propagated from face 106 of prism 20A will be shaped in the form of an arc opening upward. A graphical illustration of this image as represented by template image array TIA is shown in FIG. 34. Although line 254 is graphically illustrated in FIG. 34, it is to be understood that the shading is actually represented by the magnitude pixel values $PV_{n,mT}$ at the particular pixel locations.

Curvature correction data is generated from template image array TIA in the following manner. All curvature distortion inherent in the transfer function of prism 20A occurs along a y -axis parallel to a vertical line through the longitudinal axis of the finger when positioned in groove 102 of prism 20A (and generally parallel to surface 106). Furthermore, it is assumed that all pixel values $PV_{n,m}$ for any column $1 \leq m \leq M$ within template image array TIA are distorted by the same amount. That is, the amount of distortion for all pixel values $PV_{1 \leq n \leq N, M}$, for example, are equal.

Were line 254 undistorted by the optical properties of prism 20A, the pixel values $PV_{n,m}$ representing line 254 (e.g., $PV_{2,1T}$, $PV_{2,2T}$, $PV_{3,3T}$, $PV_{3,4T}$) would all be adjacent one another in the same row (e.g., $n=9$) within template image array TIA . Curvature correction data for pixel values $PV_{n,mT}$ for each column $1 \leq m \leq M$ can therefore be defined in terms of an offset OFF_m from an expected position, where m is the column within array

TIA . For purposes of example, it will be assumed that all of the pixel values illustrated in FIG. 34 which represent line 254 should actually be positioned in row $n=9$. Offsets OFF_m can be expressed in terms of the number of pixel locations $PL_{n,m}$ by which the pixel value $PV_{n,mT}$ is vertically displaced from its proper location (e.g. row $n=9$). Using the example shown in FIG. 32, OFF_1 and OFF_2 equal seven, OFF_3 and OFF_4 equal six and OFF_9 and OFF_{10} equal three. Following this procedure, a curvature correction table of curvature correction or offset data OFF_1-OFF_M (illustrated in FIG. 33 for array TIA shown in FIG. 34) is generated by computer 200 and stored in RAM 202 or ROM 204.

Computer 200 utilizes the offset data in the curvature correction table to generate curvature corrected array CCA of curvature corrected pixel values $PV_{n,mC}$ from un-haired array UA . Computer 200 does this by determining pixel values $PV_{n,mC}$ of curvature corrected array CCA as a function of the pixel values $PV_{n,mU}$ in the un-haired array and offsets OFF_m , as described by equation 33, below.

$$PV_{n,mC} = PV_{n - OFF_m, mU} \quad \text{Eq. 33.}$$

Using the offsets of the example illustrated in FIG. 32 and described above and in the table illustrated in FIG. 33, for example, $PV_{9,1C} = PV_{9-7,1U} = PV_{2,1U}$, $PV_{9,9C} = PV_{9-3,9U} = PV_{6,9U}$. Similarly $PV_{10,9C} = PV_{7,9U}$.

Following the above procedure a curvature corrected array CCA of curvature corrected pixel values $PV_{n,mC}$ can be produced. For those pixel values $PV_{n,mC}$ for $1 \leq n < OFF_m$ of a given row $1 \leq m \leq M$ of curvature corrected array CCA there will obviously be no pixel values $PV_{h,mU}$ within un-haired array UA to "translate." These pixel values $PV_{n,mC}$ are simply set equal to PV_{MAX} or PV_{MIN} , as they define the edge of the fingerprint image represented by array CCA .

The above procedure has been described for finger prism 20A. However, due to the different characteristics of groove 102 of prisms 20A-20D, a separate table of curvature correction data such as that illustrated in FIG. 33 will be generated by computer 200 for each prism. Computer 200 will then utilize the table of curvature correction data corresponding to the particular prism 20A-20D from which the image being processed was propagated, to curvature correct the un-haired array UA representative of the image.

F. Vertical Scaling

As previously discussed, fingerprint images produced by finger prisms 20A-20D and slap print prisms 18 and 18' will have vertical or Y -axis size or scale errors due to the observation OA at which fingerprint 134 of finger 132 is imaged (FIG. 15). This vertical scale error is compounded on fingerprint images produced by finger prisms 20A-20D since portions of fingerprint 134 near tip 145 curve upward, effectively increasing the observation angle at these locations. This vertical scale error can also be thought of a parallax error. Since the image is taken at an angle other than 90° with respect to the "plane" of the fingerprint, true distances along Y -axis 141 which are parallel to the longitudinal axis 139 of finger 132 are "compressed", along the vertical axis of the fingerprint image such as that represented by curvature corrected array CCA . In other portions of the image, distances about Y -axis 141 can be "expanded" from their true distance on the fingerprint.

To correct those vertical scale errors, computer 200 processes curvature corrected array CCA in accordance with a Vertical Scaling program to generate a vertically scaled array VA of vertically scaled pixel values $PV_{n,m}$ as illustrated in FIG. 35. A table of vertical scale correction data is generated for each prism 20A-20D, 18 and 18' within system 10, and stored in either RAM 202 or ROM 204. Computer 200 utilizes the table of vertical scale correction data to generate vertically scaled array VA.

The generation of the table of vertical scale correction data for prism 18 (which is representative of a generation of vertical scaling correction data for prisms 20A-20D and 18') is described with reference to FIG. 36. As shown, a template 270 will have a pattern of indicia 272A-272H which are spaced about a Y-axis 274 by known and preferably equal distances D30. Template 270 is positioned on finger-receiving surface 150 of prism 18 with axis 274 oriented parallel to a longitudinal axis such as 139 of a finger such as 132 when positioned on prism 18. An image 276 of the pattern of indicia 272A-272H will be propagated from image propagation surface 156, imaged by camera 28 (FIG. 2), and the data representative of this image processed by computer 200 in accordance with the various programs described above until a curvature corrected array CCA of image 276 is generated.

A portion of a curvature corrected array CCA representative of image 276 and the pattern of indicia 272A-272H is illustrated diagrammatically in FIG. 37. Indicia 272A-272E are illustrated graphically in FIG. 37 for purposes of example. However, it is to be understood that the magnitude of the image at the particular pixel locations of indicia 272A-272H in curvature corrected array CCA are actually represented by pixel values $PV_{n,m}$.

Since indicia 272A-272H are separated by known distances on template 270, these known distances would correspond to predetermined numbers of pixel location $PL_{n,m}$ in the vertical or "n" direction of curvature corrected array CCA. In the embodiment of template 270 illustrated in FIG. 36, indicia 272A-272H are separated by equal known distances D30. Were there no vertical scale error, the representation of each indicia 272A-272H would be separated from each other in the vertical direction of array CCA by the same predetermined number (e.g., three) pixel locations $PL_{n,m}$. However, due to the scale errors inherent in prism 18, indicia 272A-272H will be separated by differing numbers of pixel locations $PL_{n,m}$. In the example shown in FIG. 37, indicia 272A and 272B are compressed, separated by no pixel locations $PL_{n,m}$, and adjacent to one another. Indicia 272B and 272C are also compressed, but not quite as much, and are separated by one pixel location $PL_{n,m}$. Indicia 272D and 272E, on the other hand, are vertically expanded from their normal positional relationship, and separated by four pixel locations $PL_{n,m}$.

A table 280 of vertical scale correction data generated by computer 200 is illustrated graphically in FIG. 38. Data within table 280 characterizes locations of pixel values $PV_{n,m}$ in vertically scaled array VA as a function of the vertical location within curvature corrected array CCA at which the pixel value should be taken. With respect to FIG. 37, for example, it is assumed that pixel values $PV_{200,m}$ will be correctly positioned in the same row of vertically scaled array VA. That is, pixel values $PV_{200,m} = PV_{200,m}$. However, it is known that indicia 272B should be spaced

from 72A by three pixel locations $PL_{n,m}$ in the example used above. Pixel values $PV_{201,m}$ of curvature corrected array CCA should therefore be positioned in row 204 of vertically scaled array VA. Table 280, therefore, includes data which characterizes pixel values $PV_{204,m}$ as being equal to pixel values $PV_{201,m}$ of curvature corrected array CCA.

Since indicia 272A and 272B were compressed due to the optical transfer properties of prism 18, information therebetween is lost. Computer 200 thereby "fills in" this lost information by inserting or repeating pixel values $PV_{201,m} - PV_{203,m}$ of vertically scaled array VA with information at one of either pixel values $PV_{200,m}$ or $PV_{201,m}$ of the curvature corrected array CCA. In the embodiment shown in FIG. 38, all pixel values $PV_{201,m} - PV_{203,m}$ are set equal to pixel value $PV_{201,m}$ of curvature corrected array CCA.

Following the above example, it is also known that indicia 272C should be spaced vertically from indicia 272B by three pixel locations $PL_{n,m}$. All pixel values $PV_{203,m}$ of the 203rd row in curvature corrected array CCA should therefore actually be positioned in the 208th row of vertically scaled array VA. Accordingly, computer 200 generates data within table 280 associating pixel values $PV_{203,m}$ of curvature corrected array CCA with pixel values $PV_{208,m}$ of the vertically scaled array VA. Portions of the image which were lost due to compression between indicia 272B and 272C are "filled in" by repeating pixel values $PV_{202,m}$ of the curvature corrected array CCA at pixel values $PV_{205,m} - PV_{207,m}$ of vertically scaled array VA. Data characteristic of this filling in or repetition of pixel values is characterized in table 280. Procedures similar to those described above are repeated for pixel value $PV_{212,m}$ of vertically scaled array VA which should actually be equal to pixel values $PV_{206,m}$ in curvature corrected array CCA.

Indicia 272D and 272E would also be separated by three pixel locations $PL_{n,m}$ were no vertical scaling errors inherent in prism 18. However, indicia 272D and 272E have been "expanded" by the optical properties of prism 18, and they are actually separated by four pixel locations $PL_{n,m}$. In other words, pixel values $PV_{211,m}$ in curvature corrected array CCA should actually be spaced from pixel values $PV_{212,m}$ of vertically scaled array VA (which correspond to pixel values $PV_{206,m}$ in curvature corrected array CCA) by three pixel locations $PL_{n,m}$. Accordingly, computer 200 causes data representative of the fact that pixel values $PV_{216,m}$ of vertically scaled array VA should actually be equal to pixel values $PV_{211,m}$ of curvature corrected array CCA in table 280.

Since indicia 272D and 272E were expanded, portions of the image therebetween are redundant and must be eliminated. In this particular example, one row of pixel values $PV_{n,m}$ must be eliminated from the curvature corrected array CCA. In generating vertical scaling correction data in table 280, computer 200 has eliminated pixel values $PV_{208,m}$ of curvature corrected array CCA.

The above procedure is carried out for all pixels $PV_{1,m} - PV_{N,m}$ of vertically scaled array VA to generate vertical scale correction data in table 280 which characterizes the row within curvature corrected array CCA from which each row of pixel values $PV_{n,m}$ of vertically scaled array VA should be taken. It has been found, however, that by vertically scaling

the image in this manner, that there will be no corresponding pixels PV_{n,m_C} in curvature corrected array CCA which are properly translated to positions near the top and bottom edges of vertically scaled array VA. These portions of vertically scaled array VA, typically 5 for rows n less than 100 and n greater than 400 for a 512 pixel array, are set equal to PV_{MAX} so they will be represented as white in the output image. Computer 200 causes data representative of this inherent feature to be stored in table 280 of vertical scaling correction data as illustrated in FIG. 38. 10

To generate vertically scaled array VA, computer 200 utilizes data stored in memory and representative of table 280 (vertical scale correction data) along with pixel values PV_{n,m_C} of curvature corrected array CCA. For each pixel value PV_{n,m_V} of vertically scaled array VA, computer 200 accesses table 280 to determine from which row of curvature corrected array CCA the pixel value PV_{n,m_C} should be taken. For example, to produce a vertically scaled array VA from curvature 15 corrected array CCA shown in FIG. 31 utilizing vertical scale correction data in table 280, pixel values PV_{200,m_V} will be set equal to corresponding pixel values PV_{200,m_C} of curvature corrected array CCA. Pixel values $PV_{200,200_V}$ of vertically scaled array VA 25 will, for example, be set equal to pixel value $PV_{200,200_C}$ of curvature corrected array CCA. Following a similar approach, pixel values PV_{211,m_V} of vertically scaled array VA will be said equal to corresponding pixel values PV_{205,m_C} . Pixel value $PV_{211,200_V}$ of vertically scaled array VA will, for example, be set equal to pixel value $PV_{205,200_C}$ of curvature corrected array CCA. Utilizing the scaling data in table 280, all pixel values PV_{1,m_V} and PV_{n,m_V} are set equal to values PV_{MAX} . Computer 200 will then store data representative of vertically scaled array VA in RAM 202. 35

G. Horizontal Scaling

As previously discussed, fingerprint images produced by finger prisms 20A-20D will have horizontal or X-axis size or scale errors due to the observation angle OA 40 at which finger 134 of finger 132 is imaged, and the fact that portions of the fingerprint are positioned about a curved surface such as that represented by X-base curve axis 140 at sides 144 of fingerprint 143. Since the image 45 is taken at an observation angle other than 90° with respect to the "plane" of the fingerprint at any particular point, two distances along X-axis 140 are "compressed" along the horizontal axis of the fingerprint image such as that represented by vertically scaled 50 array VA. In other portions of the image, distances about X-axis 140 can be "expanded" from their true distance on the fingerprint.

To correct for these horizontal scale errors, computer 200 processes vertically scaled array VA in accordance with a Horizontal Scaling program to generate a horizontally scaled array HA of horizontally scaled pixel values PV_{n,m_H} as illustrated in FIG. 39. A table 310 of vertical scale correction data such as that illustrated in FIG. 40 is generated for each prism 20A-20D 60 within system 10, and stored in either RAM 202 or ROM 204. Computer 200 utilizes the table such as 310 of horizontal scale correction data to generate horizontally scaled array HA.

The generation of a table 310 of horizontal scale 65 correction data for prism 20A (which is representative of generation of tables of horizontal scale correction data for prisms 20A-20D) is described initially with

reference to FIG. 32. As shown in FIG. 32, a template 250 has a pattern of indicia 252 which includes hatch marks 256A-256G spaced about a line 254 by known and preferably equal distances. Template 250 is then shaped to conform to groove 102 of prism 20A, and positioned within the group in such a manner that line 254 is perpendicular to a longitudinal axis of the groove. This procedure is performed in a manner identical to that previously described with reference to the Curvature Correction program. An image of pattern of indicia 252 and hatch marks 256A-256G will be propagated from image propagation surface 106, imaged by camera 28 (FIG. 2), and data representative of this image processed by computer 200 in accordance with the various programs described above until a vertically scaled array VA of the image is generated.

A portion of vertically scaled array VA representative of the image of hatch marks 256A-256E is illustrated diagrammatically in FIG. 41. Indicia 256A-256E are illustrated graphically in FIG. 41 for purposes of example. However, it is to be understood that the magnitude of the image at the particular pixel locations of indicia 256A-256E in vertically scaled array VA are actually represented by pixel values PV_{n,m_V} .

Since hatch marks 256A-256E are separated by known distances on template 250, these known distances would correspond to predetermined numbers of pixel locations $PL_{n,m}$ in the horizontal or "m" direction of vertically scaled array VA. In the embodiment of template 250 illustrated in FIG. 32, hatch marks 256A-256G are separated by known distances. Were there are no horizontal scale error, the representation of each hatch mark 256A-256G would be separated from each other in the horizontal direction of array VA by the same predetermined number (e.g., three) pixel locations $PL_{n,m}$. However, due to the scale errors inherent in prism 20A, hatch marks 256A-256G will be separated by differing numbers of pixel locations $PL_{n,m}$. In the example shown in FIG. 41, hatch marks 256A and 256B are compressed, separated by no pixel locations $PL_{n,m}$, and adjacent to one another. Hatch marks 256B and 256C are compressed, but not quite as much, and are separated by one pixel location $PL_{n,m}$. Hatch marks 256D and 256E, on the other hand, are horizontally expanded from their normal positional relationship, and separated by four pixel locations $PL_{n,m}$.

Data within table 310 characterizes locations of pixel values PV_{n,m_H} in horizontally scaled array HA as a function of the horizontal location within vertically scaled array VA at which the pixel value should be taken. With respect to FIG. 41, for example, it is assumed that pixel values $PV_{n,300_V}$ will be correctly positioned in the same row of the horizontally scaled array HA. That is, pixel values $PV_{n,300_H} = PV_{n,300_V}$. However, it is known that hatch mark 256B should be spaced from 256A by three pixel locations $PL_{n,m}$ in the example used above. Pixel values $PV_{n,301_V}$ of vertically scaled array VA should therefore be positioned in column 304 of horizontally scaled array HA. Table 310, therefore, includes data which characterizes pixel values $PV_{n,304_H}$ as being equal to pixel values $PV_{n,301_V}$ of vertically scaled array VA.

Since hatch marks 256A and 256B were compressed due to the optical transfer properties of prism 20A, information therebetween is lost. Computer 200 thereby "fills in" this lost information by inserting or repeating pixel values $PV_{n,301_H} - PV_{n,303_H}$ of horizontally scaled array HA with information at one of either pixel

values $PV_{n,300V}$ or $PV_{n,301V}$ of the vertically scaled array VA. In table 310, all pixel values $PV_{n,301H}$ – $PV_{n,303H}$ are set equal to pixel values $PV_{n,301V}$ of vertically scaled array VA.

Following the above example, it is also known that hatch mark 256C should be spaced horizontally from hatch mark 256B by three pixel locations $PL_{n,m}$. All pixel values $PV_{n,303V}$ of the 303rd column in the vertically scaled array VA should therefore actually be positioned in the 208th column of horizontally scaled array VA. Accordingly, computer 200 generates data within table 310 associating pixel values $PV_{n,303V}$ of vertically scaled array VA with pixel values $PV_{n,308H}$ of the horizontally scaled array HA. Portions of the image which were lost due to the compression between hatch marks 256B and 256C are "filled in" by repeating pixel values $PV_{n,302V}$ of the vertically scaled array VA at pixel values $PV_{n,305H}$ – $PV_{n,307H}$ of horizontally scaled array HA. Data characteristic of this filling in or repetition of pixel values is characterized in table 310. Procedures similar to those described above are repeated for pixel values $PV_{n,312H}$ of horizontally scaled array HA which should actually be equal to pixel values $PV_{n,306V}$ of the vertically scaled array VA.

Hatch marks 256D and 256E would also be separated by three pixel locations $PL_{n,m}$ were no vertical scaling errors inherent in prism 20A. However, hatch marks 256D and 256E have been "expanded" by the optical properties of prism 20A, and they are actually separated by four pixel locations $PL_{n,m}$. In other words, pixel values $PV_{n,311V}$ in vertically scaled array VA should actually be spaced from pixel values $PV_{n,312H}$ of horizontally scaled array HA (which correspond to pixel values $PV_{n,306V}$ in vertically scaled array VA) by three pixel locations $PL_{n,m}$. Accordingly, computer 200 causes data representative of the fact that pixel values $PV_{n,316H}$ of horizontally scaled array HA should actually be equal to pixel values $PV_{n,311V}$ of vertically scaled array VA in table 310.

Since hatch marks 256D and 256E were expanded, portions of the image therebetween are redundant and must be eliminated. In this particular example, one column of pixel values $PV_{n,mV}$ must be eliminated from the vertically scaled array VA. In generating horizontal scale correction data in table 310, computer 200 has eliminated pixel values $PV_{n,308V}$ of vertically scaled array VA.

The above procedure is carried out for all pixel values $PV_{n,1H}$ – $PV_{n,MH}$ of horizontally scaled array HA to generate horizontal scale correction data in table 310 which characterizes the column within vertically scaled array VA from which each column of pixel values $PV_{n,mH}$ of horizontally scaled array HA should be taken. It has been found, however, that by horizontally scaling the image in this manner, that there will be no corresponding pixel values $PV_{n,mV}$ which are properly translated to positions near the left and right edges of horizontally scaled array HA. These portions of horizontally scaled array HA, typically for columns m less than 100 and m greater than 400 for a 512 pixel array are set equal to PV_{MAX} so that they will be represented as white in the output image. Computer 200 causes data representative of this inherent feature to be stored in table 310 of horizontal scale correction data as illustrated in FIG. 40.

To generate horizontally scaled array HA, computer 200 utilizes data stored in memory and representative of table 310 (horizontal scale correction data) along with

pixel values $PV_{n,mV}$ of vertically scaled array VA. For each pixel value $PV_{n,mH}$ of horizontally scaled array HA, computer 200 accesses table 310 to determine from which column of vertically scaled array VA the pixel value $PV_{n,mH}$ should be taken. For example, to produce horizontally scaled array HA from vertically scaled array VA shown in FIG. 35 utilizing horizontal scale correction data in table 310, pixel values $PV_{n,300H}$ will be set equal to corresponding pixel values $PV_{n,300V}$ of vertically scaled array VA. Pixel values $PV_{300,300H}$ of horizontally scaled array HA will, for example, be set equal to pixel value $PV_{300,300V}$ of vertically scaled array VA. Following a similar approach, pixel values $PV_{n,311H}$ of horizontally scaled array HA will be set equal to corresponding pixel values $PV_{n,305V}$. Utilizing the scaling data in table 310, all pixel values $PV_{n,1H}$ and $PV_{n,MH}$ are set equal to values PV_{MAX} . Computer 200 will then store data representative of horizontally scaled array HA and RAM 202.

H. Threshold

After the digital data representative of fingerprint 143 (FIG. 15) has been imaged by camera 28 and processed by computer 200 in accordance with the Noise Average, Illumination Equalization, Directional Filter, Unhair, Curvature Correction, and Vertical and Horizontal Scaling programs, a horizontally scaled array HA of horizontally scaled pixel values $PV_{n,mH}$ representative of the fingerprint image is stored in RAM 202. Each pixel value $PV_{n,mH}$ is an eight-bit digital value representing intensity of the image at that particular discrete or pixel location $PL_{n,m}$. This data will be utilized by printer 16 to print an enhanced visual representation of the fingerprint image.

In one embodiment, printer 16 is a matrix printer capable of printing in a gray scale at discrete locations. When system 10 includes a printer 16 of this type, computer 200 retrieves pixel values $PV_{n,mH}$ of horizontally scaled array HA from RAM 202, maps these pixel values into a proper format, and transmits this data to the printer. Printer 16 will then print a visual representation of the fingerprint image with the intensity at each discrete printed location determined by the pixel value $PV_{n,mH}$.

In another embodiment, printer 16 is a dot matrix printer, and incapable of utilizing pixel values $PV_{n,mH}$ to print a gray scale image at discrete locations or dots. At each discrete location on applicant card 15, printer 16 can either leave the spot blank, or make it black. As a result, computer 200 implements a Threshold program to determine whether each pixel value $PV_{n,mH}$ of the horizontally scaled array HA should be represented as a white or black spot by printer 16 on card 15.

Implementing the Threshold program, computer 200 compares each pixel value $PV_{n,mH}$ to a print threshold value TP. If the pixel value $PV_{n,mH}$ is less than the threshold value TP, this pixel value is to represent a "black" or printed region on applicant card 15, and computer 200 accordingly sets the pixel value to zero or "0". If the pixel value $PV_{n,mH}$ is greater than or equal to threshold value TP, this particular pixel value is to represent a white portion of the image, and computer 200 accordingly sets a pixel value equal to one or "1". Threshold value TP can vary depending upon a desired appearance of the fingerprint image. In one embodiment, threshold value TP is a digital value representative of an intensity halfway between the two hundred and fifty-six (i.e. 128) possible intensity values which

can be represented by eight-bit pixel values $PV_{n,mH}$. If it is desired to have the black portions of the printed fingerprint image (valleys 138) to have a finer width, threshold value TP should be set to a value lower than 128. If it is desired to have the white portions of the image (ridges 136) to have a finer width, threshold value TP should be set to a level higher than 128.

Having generated a Thresholded array of enhanced pixel values $PV_{n,mH}$, computer 200 stores these pixel values in RAM 202. In response to print signals, computer 200 will transmit these bits sequentially in a standard printer format to printer 16. In response, printer 16 will print the enhanced fingerprint image onto applicant card 15.

System Operation

Operation of fingerprinting system 10 is described with reference to FIGS. 1 and 42-47. Upon initial power-up, computer 200 will run a series of diagnostics which verify correct operation of computer 200, RAM 202, and ROM 204. After passing these diagnostics, data terminal 6 will generate a copyright notice which will be displayed on monitor 7 for several seconds. Following the copyright notice, data terminal 6 will generate and display on its monitor 8 a Main Display menu 300 illustrated in FIG. 42.

Having reviewed the available options presented on menu 300, an operator can select Option 1 by sequentially pressing the "1" and RETURN keys of keyboard 7 of data terminal 6 whenever a new booking is being processed. System 10 is then cleared of information from a previous booking, and reset so as to be ready to accept new information.

If it is desired to initiate fingerprint capture or recording, the operator can select option 2 by sequentially pressing the "2" and RETURN keys of keyboard 7. In response, data terminal 6 will generate and display Processing Choices menu 302 illustrated in FIG. 46. Having reviewed the available options presented on menu 302, if the operator desires not to capture fingerprints, they will select Option 0 from menu 302 by sequentially pressing the "0" and RETURN keys of keyboard 7. Data terminal 8 will then redisplay Main Display menu 300. Should the operator desire to capture fingerprints, Option 1 from menu 302 will be selected by sequentially pressing the "1" and RETURN keys of keyboard 7. Option 2 from menu 302 is selected if it is desired to capture only one fingerprint. This is done if it is desired to test system capabilities, or to edit a poor previously captured print. Option 2 is selected when the operator sequentially presses the "2" and RETURN keys of keyboard 7.

If an operator desires to change capture options, Option 3 is selected by sequentially pressing the "3" and RETURN keys of keyboard 7. In response to this option, the operator will be asked a series of questions by means of prompts displayed on monitor 8 of data terminal 6. These questions are answered by pressing the "Y" key of keyboard 7 to answer "yes", or by pressing the "N" key to answer "no." Options which can be selected in this manner include a High Contrast Capture Option which allows a very quick capture of print, but with relatively low quality due to the high contrast. The operator can also get an enlarged printed copy of one of the prints if desired. If the Enlarged Print Option is selected, both a life-size and four times normal size image of a fingerprint can be printed by printer 16. Also, the operator is asked if they would like to approve

the print twice. The first chance to approve the print comes after capture, and the second chance comes after the image has been visually enhanced by the image enhancement software programs. Typically, prints are approved only once, that being after processing has been completed.

When Option 1 from menu 302 is selected, system 10 enters a capture mode during which all ten individual fingerprints, plus slap prints from both the left and right hands, will be captured. This procedure is implemented with the assistance of key pad 19 and display 13 on optics/processor unit 12.

Having selected Option 1 from menu 302 when it is desired to capture fingerprints, computer 200 will first actuate motor 76 to drive slap/finger image selection optics 26 to the finger prism select position illustrated in FIG. 2 (if optics 26 is not already so positioned). Signals representative of this positioning are provided to computer 200 by microswitch 89, where upon actuation of motor 76 is terminated. Computer 200 will then cause LED 316A of left hand indicia 312 to be lit, indicating a prompt that a fingerprint of the left thumb is to be captured. Simultaneously, computer 200 cause LEDs 21C and 21D to be lit, thereby illuminating keys 17C and 17D. The operator will then move trolley 42, using lever 52, to position a finger prism 20A-20D having the properly sized groove 102 for the thumb of the particular person being fingerprinted within aperture 51. The person being fingerprinted will then position their thumb within groove 102 of the selected prism 20A-20D, and adjust their finger within the groove while the operator observes image quality on monitor 14. When an image which it is desired to capture is displayed on monitor 14, the operator will actuate CAPTURE key 17C on key pad 19. This image is then "frozen", with digitizer 206 digitizing the data provided by TV camera 24. This data is then processed in accordance with the software programs described above to produce an array of data characterizing the enhanced fingerprint image. This data is then stored within RAM 202. If the person being fingerprinted was an amputee and did not have a left thumb, the operator would have actuated AMP key 17D. Computer 200 then stores data characteristic of this action.

If the "approve print twice" option was previously selected, the operator can further examine the image on monitor 14 prior to its being processed. If this option was selected, computer 200 will cause LEDs 21A and 21B to be lit, illuminating keys 17A and 17B to indicate that one of these keys is the correct response. If it is desired to continue processing this image, YES key 17A is actuated. If after further study, it is decided that this image is not acceptable, NO key 17B is actuated.

After the capture and processing of the left thumb fingerprint, computer 200 will cause LED 316B to be illuminated thereby prompting the operator that the left index finger is to be fingerprinted. The above described procedures are then repeated, with prompts for each of the ten fingers of the two hands of the person being fingerprinted being made.

After all ten fingers have been individually fingerprinted in the above-described manner, a prompt will be displayed on monitor 8 of data terminal 6 indicating that slap or plain prints for the left hand are to be taken. Computer 200 will also actuate motor 76 so as to drive mounting plate 60 to its slap print image selection position. Computer 200 will receive a signal from microswitch 87, and deactivate motor 76, when selection

optics 26 are properly positioned at the slap image position illustrated in FIG. 3B. CAPTURE key 17C and AMP key 17D will also be lit. The person to be fingerprinted will then position the index, middle, ring and little fingers of the left hand on finger receiving surface 150 of slap print prism 18'. When the operator observes a high quality image on monitor 14, they will press CAPTURE key 17C which "freezes" this image, and causes it to be processed by the image enhancement software of processor subsystem 30. Data representative of this slap print image is then stored in RAM 202. This procedure is then repeated for the slap or plain prints of the right hand.

After the slap prints have been taken, Main Display menu 300 which is shown in FIG. 42 will again be displayed on monitor 8 of data terminal 6. The operator can then select Option 3 to enter demographic information regarding the person whose fingerprints have just been taken as well as to enter department information used by the police or other organization performing the fingerprinting. When Option 3 is selected, data terminal 6 will display on its monitor 8 a Demographic/Department Information menu such as 320 (FIG. 45) which requests the operator to enter all necessary demographic and department information. The operator can then enter this demographic information using the various keys of keyboard 7 of data terminal 6 in a standard manner. Main Display menu 300 can then again be displayed when the operator presses the RETURN key once all demographic and department information has been entered into terminal 6.

After all fingerprints have been captured and demographic/department information entered, the operator can select Option 4 to have all of this information printed on a standardized booking or applicant card

such as 15 illustrated in FIG. 47. Applicant card 15 has standardized locations for all the various fingerprints which have been captured, as well as the demographic information and department information which has been entered into terminal 6. Card 15 will be inserted into printer 16 in an indexed manner. When Option 4 is selected, computer 200 causes all of the information retrieved from RAM 202 and to be printed at the proper locations on card 15.

Conclusion

In conclusion, the optical fingerprinting system of the present invention offers a number of significant advantages over those of the prior art. Both individual fingerprint and slap print images can be optically obtained. A real-time display of the fingerprint being imaged can be observed and analyzed prior to its capture. Grooves within the finger prisms are contoured in such a manner as to provide an optimum amount of contact between the fingerprint and the prism. The lens trolley, which has finger prisms with a variety of different sized grooves, permits use of the system with a wide range of finger sizes. The lensed surface of the finger and slap prisms reduces vertical and horizontal scale errors, as well as curvature correction errors. Furthermore, remaining scale and curvature errors are eliminated, and other characteristics of the fingerprint image greatly enhanced, through the use of the Image Enhancement programs. The system is also designed to be very user friendly.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

```

Average - Average pixel with neighbors
Address Object      Statement
                                xdef   Average
00000001           section 1
                                include macros.def      include macro definitions
00000001           NOLIST
                                NOLIST
                                include global.def      include global symbol definitions
## Global.def - global symbol definitions.
#
# Copyright (C) 1986, CFA Technologies, Inc.
#### Intensity level definitions.
00000000           L0    equ    0
00000010           L1    equ    16
00000020           L2    equ    32
00000030           L3    equ    48
00000040           L4    equ    64

```

Address	Object	Statement.
00000050	L5	equ 80
00000050	L6	equ 96
00000070	L7	equ 112
00000080	L8	equ 128
00000090	L9	equ 144
000000A0	L10	equ 160
000000B0	L11	equ 176
000000C0	L12	equ 192
000000D0	L13	equ 208
000000E0	L14	equ 224
000000FF	L15	equ 255
	****	Useful constants.
00000009	Yshift	equ 9 ; log 2 of X and Y coordinate bounds
000001FF	Border	equ (1<<(Yshift))-1 ; X and Y coordinate border
	****	Character constants.
00000020	Space	equ \$20
00000007	Bel	equ 'G'-\$40
00000008	BS	equ 'H'-\$40
00000009	Tab	equ 'I'-\$40
0000000A	LF	equ 'J'-\$40
0000000C	FF	equ 'L'-\$40
0000000D	CR	equ 'M'-\$40
0000000E	SO	equ 'N'-\$40
0000000F	SI	equ 'O'-\$40
00000011	Xon	equ 'Q'-\$40
00000013	Xoff	equ 'S'-\$40
0000001B	Esc	equ 'E'-\$40
0000007F	Del	equ \$7f
00000019	CtrlY	equ 'Y'-\$40
	****	Constants used to control LEDs
	*	Legal codes for ButtonLight (SwitchOff also good for FingerLight)
00000000	SwitchOff	equ 0
00000001	YesAndNo	equ 1
00000002	Capture	equ 2
00000003	SwitchTest	equ 3
	*	Codes to control fluorescent lights
00000001	FluorRoll	equ 1
00000002	FluorSlap	equ 2
	****	Assembly constants.
	**	Background fill value.


```

Address Object      Statement
000000FF      BackFill      equ      LIS           white

##      Assembly options.

FFFFFFF      StandardAverage equ      true           use (1,2,1) (2,4,2) (1,2,1) average
00000000      HorizAverage equ      false          use (0,0,0) (1,2,1) (0,0,0) average

###

###      Average - Average pixel with neighbors.
#      Original version by M. S. Ranson.
#      Implemented in 68000 assembly language and
#      modified to run without buffers by D. E. Gerwinn.
#
#      entry (a1) = address of input image screen buffer
#      NOTE: There MUST be free memory of size 2*(Border+1)
#            bytes before the input screen image.
#
#      exit (a1) = address of averaged image.
#
#      uses  a - 1
#            d - none.
#
#      calls none.

Average
! 000000 48E7F038      movem.l a2-a4/d0-d3, -(sp)      save registers
! 000004 2449          move.l a1, a2
! 000006 95FC00000400    sub.l #2*(Border+1), a2          compute address of output image
! 00000C 2649          move.l a1, a3                    copy input and output pointers
! 00000E 284A          move.l a2, a4
! 000010 D7FC000001FF    add.l #Border, a3                set up for loop entry
! 000016 D9FC000001FF    add.l #Border, a4
! 00001C 7600          moveq #0, d3                     clear pixel register
! 00001E 323C01FD      move.w #Border-2, d1             y := 1 to Border-1 (d1 counts down)
! 000022 303C01FD      avg1 move.w #Border-2, d0          x := 1 to Border-1 (d0 counts down)
! 000026 548B          addq.l #2, a3                    point counters at next line
! 000028 548C          addq.l #2, a4
! 00002A 7400          avg2 moveq #0, d2                     clear sum

+      ift      StandardAverage
+      IFNE     StandardAverage
! 00002C 1413          move.b (a3), d2                  sum := 4 * pixel(x,y)
! 00002E D442          add.w d2, d2
! 000030 162BFFFF    move.b -(a3), d3
! 000034 D443          add.w d3, d2                      + 2 * pixel(x-1,y)
! 000036 162B0001    move.b 1(a3), d3
! 00003A D443          add.w d3, d2                      + 2 * pixel(x+1,y)
! 00003C 162BFEE0    move.b -(Border+1)(a3), d3
! 000040 D443          add.w d3, d2                      + 2 * pixel(x,y-1)
! 000042 162B0200    move.b Border+1(a3), d3

```

Address	Object	Statement.	
1 000046	D443	add.w d3,d2	+ 2 * pixel(x,y+1)
1 000048	D442	add.w d2,d2	
1 00004A	162BFDFE	move.b 0-1-(Border+1)(a3),d3	
1 00004E	D443	add.w d3,d2	+ pixel(x-1,y-1)
1 000050	162BFE01	move.b 1-(Border+1)(a3),d3	
1 000054	D443	add.w d3,d2	+ pixel(x+1,y-1)
1 000056	162B01FF	move.b 0-1+(Border+1)(a3),d3	
1 00005A	D443	add.w d3,d2	+ pixel(x-1,y+1)
1 00005C	162B0201	move.b 1+(Border+1)(a3),d3	
1 000060	D443	add.w d3,d2	+ pixel(x+1,y+1)
1 000062	E84A	lsl.w #4,d2	average := sum div 16
		endr	
		ift HorizAverage	
		IFNE HorizAverage	
		move.b (a3),d2	sum := 2 * pixel(x,y)
		add.w d2,d2	
		move.b -1(a3),d3	
		add.w d3,d2	+ pixel(x-1,y)
		move.b 1(a3),d3	
		add.w d3,d2	+ pixel(x+1,y)
		lsl.w #2,d2	average := sum div 4
		endr	
1 000064	18C2	move.b d2,(a4)+	store averaged pixel and advance
1 000066	528B	addq.l #1,a3	advance to next input pixel
1 000068	51C8FFC0	dbra d0,avg2	do next pixel
1 00006C	51C9FFB4	dbra d1,avg1	do next raster line
		## Clear border areas that are garbage because average doesn't	
		* operate on the whole image.	
1 000070	70FF	moveq #(BackFill<<24)+(BackFill<<16)+(BackFill<<8)+BackFill,d0	
1 000072	323C007F	move.w #((Border+1)/4)-1,d1	
1 000076	224A	move.l a2,a1	
1 000078	22C0	avg3 move.l d0,(a1)+	clear upper raster line
1 00007A	51C9FFFC	dbra d1,avg3	
1 00007E	323C007F	move.w #((Border+1)/4)-1,d1	
1 000082	224A	move.l a2,a1	
1 000084	D3FC00040000	add.l #((Border+1)*(Border+1)),a1	
1 00008A	2300	avg4 move.l d0,-(a1)	clear lower raster line
1 00008C	51C9FFFC	dbra d1,avg4	
1 000090	224A	move.l a2,a1	
1 000092	323C01FF	move.w #Border,d1	
1 000096	1280	avg5 move.b d0,(a1)	clear left side
1 000098	134001FF	move.b d0,Border(a1)	clear right side
1 00009C	D2FC0200	add.w #Border+1,a1	position to next raster line
1 0000A0	51C9FFF4	dbra d1,avg5	
1 0000A4	224A	move.l a2,a1	return output buffer address in a1
1 0000A6	4CDF1C0F	movem.l (sp)+,a2-a4/d0-d3	restore registers and return
1 0000AA	4E75	rts	
		end	

Equalize - perform area equalization on screen image.

```

Address Object      Statement.

                                xdef    Equalize

00000001           section 1

                                include macros.def          include macro definitions
00000001           NOLIST
                                NOLIST

                                include global.def          include global symbol definitions
** Global.def - global symbol definitions.
*
* Copyright (C) 1988, CFA Technologies, Inc.

**** Intensity level definitions.

00000000           L0      equ    0
00000010           L1      equ    16
00000020           L2      equ    32
00000030           L3      equ    48
00000040           L4      equ    64
00000050           L5      equ    80
00000060           L6      equ    96
00000070           L7      equ   112
00000080           L8      equ   128
00000090           L9      equ   144
000000A0           L10     equ   160
000000B0           L11     equ   176
000000C0           L12     equ   192
000000D0           L13     equ   208
000000E0           L14     equ   224
000000FF           L15     equ   255

**** Useful constants.

00000009           Yshift  equ    9      ; log 2 of X and Y coordinate bounds
000001FF           Border  equ   (1<<Yshift)-1 ; X and Y coordinate border

**** Character constants.

00000020           Space   equ    $20
00000007           Bel     equ    'G'-$40
00000008           BS      equ    'H'-$40
00000009           Tab     equ    'I'-$40
0000000A           LF      equ    'J'-$40
0000000C           FF      equ    'L'-$40
0000000D           CR      equ    'M'-$40
0000000E           SO      equ    'N'-$40
0000000F           SI      equ    'O'-$40

```

```

Address Object      Statement.
00000011      Xon      equ      'Q'-$40
00000013      Xoff     equ      'S'-$40
00000018      Esc      equ      '['-$40
0000007F      Del      equ      $7f
00000019      CtrlY    equ      'Y'-$40

*** Constants used to control LEDs

* Legal codes for ButtonLight (SwitchOff also good for FingerLight)

00000000      SwitchOff equ      0
00000001      YesAndNo equ      1
00000002      Capture  equ      2
00000003      SwitchTest equ     3

* Codes to control fluorescent lights

00000001      FluorRoll equ     1
00000002      FluorSlap equ     2

        include equalize.def          include Equalize's symbol definitions
**      Equalize.def - Equalize's symbol definitions.
*

00000003      Grid      equ     3          size of left section of averaging grid

*** Assembly options.

00000000      LoopBackground equ     false      use blankdist for background detection
FFFFFFF      AvgBackground equ     true       use average for background detection

***

*** Assembly constants.

*      For area equalization.

00000040      TotalDots equ     (Grid+1+(Grid+1))*(Grid+1+(Grid+1))

*      For background detection using loop.

00000010      BlankVal   equ     LI          variation threshold for background
00000003      BlankDist  equ     Grid        how far to look for background

*      Background fill value for unequalized areas.

000000FF      BackFill   equ     LI5          white

```


Address Object

Statement.

```

*** Equalize - perform area equalization on screen image.
* Based on Pascal implementation by M. S. Ransom.
* Converted to 68000 assembler by O. E. Germann.
*
* Copyright (C) 1986, CFA Technologies, Inc.
*
* entry (a4.l) = input screen image address.
*       There MUST be free memory of size (Grid+1) * (Border+1)
*       before the input screen image.
*       (d0.w) = background level.
*
* exit  image converted.
*       (a5.l) = output screen image address.
*
* uses  a - 0, 1, 2, 3, 5, 6.
*       d - all.
*
* calls none.

```

VarBegin

```

00000000 +Voffset set 0
          var.w Background,l
FFFFFFFE + nolist
          array.w ColumnSum,0,Border,l
FFFFFF3FE + nolist
          VarEnd EquRam
FFFFFFBFE + nolist

```

Equalize

```

l 000000 4E56FBFE link a6,#EquRam
l 000004 3D40FFFF move.w d0,Background(a6) save background value
l 000008 2A4C move.l a4,a5
l 00000A 9BFC0000800 sub.l #(Grid+1)*(Border+1),a5 compute output image address
l 000010 7000 moveq #0,d0
l 000012 323C01FF move.w #Border,d1
l 000016 41EEFBFE lea ColumnSum(a6),a0
l 00001A 30C0 equ1 move.w d0,(a0)+ ColumnSum[i] := 0
l 00001C 51C9FFFC dbra d1,equ1
l 000020 7206 moveq #Grid+(Grid+1)-1,d1 y := 0 (d1 counts down)
l 000022 204C move.l a4,a0 addr(ScreenIn[0,0])
l 000024 343C01FF equ2 move.w #Border,d2 x := 0 (d2 counts down)
l 000028 43EEFBFE lea ColumnSum(a6),a1
l 00002C 1018 equ3 move.b (a0)+,d0 ScreenIn[x,y]
l 00002E D159 add.w d0,(a1)+ CS[x] := CS[x] + ScreenIn[x,y]
l 000030 51CAFFFA dbra d2,equ3
l 000034 51C9FFEE dbra d1,equ2
l 000038 7203 moveq #Grid,d1 y := grid
l 00003A 7C09 moveq #Yshift,d6
l 00003C 7604 equ4 moveq #Grid+1,d3
l 00003E D641 add.w d1,d3 y + grid+1

```

Address	Object	Statement.	
1 000040	EDA3	asl.l d6,d3	convert to y-coordinate
1 000042	244C	move.l a4,a2	
1 000044	D5C3	add.l d3,a2	addr(ScreenIn[0,y+grid+1])
1 000046	343C01FF	move.w #Border,d2	x := 0 (d2 counts down)
1 00004A	41EEFBFE	lea ColumnSum(a6),a0	
1 00004E	101A	equ5 move.b (a2)+,d0	ScreenIn[x,y+grid+1]
1 000050	D158	add.w d0,(a0)+ ~	CS[x] := CS[x] + ScreenIn[x,y+grid+1]
1 000052	51CAFFFA	dbra d2,equ5	
1 000056	2A3C0000020	move.l #TotalDots/2,d5	sum := TotalDots div 2 (0.5 to round)
1 00005C	7606	moveq #Grid+(Grid+1)-1,d3	i := 0 (d3 counts down)
1 00005E	45EEFBFE	lea ColumnSum(a6),a2	
1 000062	DA5A	equ6 add.w (a2)+,d5	sum := sum + ColumnSum[i]
1 000064	51CBFFFC	dbra d3,equ6	
1 000068	45EEFC04	lea ColumnSum+(Grid*2)(a6),a2	addr(ColumnSum[Grid])
1 00006C	2601	move.l d1,d3	
1 00006E	EDA3	asl.l d6,d3	
1 000070	5683	addq.l #6grid,d3	
1 000072	224C	move.l a4,a1	
1 000074	D3C3	add.l d3,a1	addr(ScreenIn[Grid,Y])
1 000076	2640	move.l a5,a3	
1 000078	D7C3	add.l d3,a3	addr(ScreenOut[Grid,y])
1 00007A	7403	moveq #6grid,d2	x := grid
1 00007C	DA6A0008	equ7 add.w 2*(Grid+1)(a2),d5	sum := sum + ColumnSum[x+grid+1]
1 000080	1011	move.b (a1),d0	pixel := ScreenIn[x,y]
		ifne LoopBackground	
		moveq #1,d3	i := 1 (offset for x)
		move.w #1<<Yshift,d4	(offset for y)
	equ8	neg.w d4	
		moveq #0,d7	
		move.b 0(a1,d4.w),d7	ScreenIn[x,y-i]
		sub.w d0,d7	pixel - ScreenIn[x,y-i]
		bge.s equ9	
		neg.w d7	abs(pixel - ScreenIn[x,y-i])
	equ9	cmp.w #BlankVal,d7	
		bgt.s equ13	if abs() > BlankVal
		neg.w d4	
		moveq #0,d7	
		move.b 0(a1,d4.w),d7	ScreenIn[x,y+i]
		sub.w d0,d7	pixel - ScreenIn[x,y+i]
		bge.s equ10	
		neg.w d7	abs(pixel - ScreenIn[x,y+i])
	equ10	cmp.w #BlankVal,d7	
		bgt.s equ13	if abs() > BlankVal
		neg.w d3	
		moveq #0,d7	
		move.b 0(a1,d3.w),d7	ScreenIn[x-i,y]
		sub.w d0,d7	pixel - ScreenIn[x-i,y]
		bge.s equ11	
		neg.w d7	abs(pixel - ScreenIn[x-i,y])
	equ11	cmp.w #BlankVal,d7	
		bgt.s equ13	if abs() > BlankVal
		neg.w d3	
		moveq #0,d7	
		move.b 0(a1,d3.w),d7	ScreenIn[x+i,y]

Address Object	51 Statement	52
	sub.w d0,d7	pixel = ScreenIn[x+i,y]
	bge.s equ12	
	neg.w d7	abs(pixel - ScreenIn[x+i,y])
	equ12 cmp.w #BlankVal,d7	
	bgt.s equ13	if abs() > BlankVal
	addq.w #1,d3	i := i + 1 (offset for x)
	add.w #1<<Yshift,d4	(offset for y)
	cmp.w #BlankDist,d3	
	ble equ8	if i <= BlankDist
	moveq #0,d3	BlankFlag := true
	endc	
1 000082 7EFF	equ13 moveq #L15,d7	preload background for blank areas
	ifne LoopBackground	
	tst.b d3	
	beq.s equ14	if BlankFlag
	endc	
1 000084 2805	move.l d5,d4	
1 00008E EC4C	ifeq TotalDots-64	
	lsl.w #6,d4	average := sum div TotalDots
	endc	
	ifne TotalDots-64	
	ifeq TotalDots-256	
	lsl.w #8,d4	average := sum div TotalDots
	endc	
	ifne TotalDots-256	
	divu #TotalDots,d4	average := sum div TotalDots
	endc	
1 000088 B86EFFFF	ifne AvgBackground	
1 00008C 6E16	cmp.w Background(a6),d4	
	bgt.s equ14	if average value is background
	endc	
1 00008E 3600	move.w d0,d3	
1 000090 9644	sub.w d4,d3	
1 000092 D67C0080	add.w #L8,d3	pixel := pixel - average + L8
1 000096 B67C00FF	cmp.w #L15,d3	
1 00009A 6E08	bgt.s equ14	if pixel > L15 then pixel := L15
1 00009C 7E00	moveq #L0,d7	preload L0 in case pixel < L0
	ifeq L0	
1 00009E 4A43	tst.w d3	
	endc	
	ifne L0	
	cmp.w #L0,d3	
	endc	

Address	Object	Statement.	
1 0000A0	6D02	blt.s equ14	if pixel < L0 then pixel := L0
1 0000A2	3E03	move.w d3,d7	output pixel is OK as it is
1 0000A4	16C7	equ14 move.b d7,(a3)+	store output pixel
1 0000A6	9A6AFFFA	sub.w -2*Grid(a2),d5	sum := sum - ColumnSum[x-grid]
1 0000AA	548A	addq.l #2,a2	advance ColumnSum pointer
1 0000AC	5289	addq.l #1,a1	advance screen pointer
1 0000AE	5242	addq.w #1,d2	x := x + 1
1 0000B0	B47C01FB	cmp.w #Border-(Grid+1),d2	
1 0000B4	6FC6	ble equ7	do next x value
1 0000B6	76FD	moveq #-Grid,d3	
1 0000B8	0681	add.l d1,d3	y-grid
1 0000BA	EDA3	asl.l d6,d3	
1 0000BC	224C	move.l a4,a1	
1 0000BE	03C3	add.l d3,a1	addr(ScreenIn[0,y-grid])
1 0000C0	45EEFBFE	lea ColumnSum(a6),a2	
1 0000C4	343C01FF	move.w #Border,d2	x := 0 (d2 counts down)
1 0000C8	1019	equ19 move.b (a1)+,d0	
1 0000CA	915A	sub.w d0,(a2)+	CS[x] := CS[x] - ScreenIn[x,y-grid]
1 0000CC	51CAFFFA	dbra d2,equ19	
1 0000D0	5241	addq.w #1,d1	y := y + 1
1 0000D2	B27C01FB	cmp.w #Border-(Grid+1),d1	
1 0000D6	6F00FF64	ble equ4	do next y value

** -Clear border areas that are garbage because Equalize doesn't
* operate on the whole image.

1 0000DA	203CFFFFFFF	equ20 move.l #(BackFill<<24)+(BackFill<<16)+(BackFill<<8)+BackFill,d0	
1 0000E0	323C017F	move.w #(((Border+1)/4)*Grid)-1,d1	
1 0000E4	224D	move.l a5,a1	
1 0000E6	22C0	equ21 move.l d0,(a1)+	clear upper raster lines
1 0000E8	51C9FFFC	dbra d1,equ21	
1 0000EC	323C01FF	move.w #(((Border+1)/4)*Grid)-1,d1	
1 0000F0	224D	move.l a5,a1	
1 0000F2	D3FC00040000	add.l #((Border+1)*Grid),a1	
1 0000F8	2300	equ22 move.l d0,-(a1)	clear lower raster lines
1 0000FA	51C9FFFC	dbra d1,equ22	
1 0000FE	224D	move.l a5,a1	
1 000100	323C01FF	move.w #Border,d1	
1 000104	7802	equ23 moveq #Grid-1,d4	
1 000106	13804000	equ24 move.b d0,0(a1,d4.w)	clear this line's left side
1 00010A	51CCFFFA	dbra d4,equ24	
1 00010E	D2FC0200	add.w #Border+1,a1	position to next raster line
1 000112	7803	moveq #Grid,d4	
1 000114	7AFF	moveq #-1,d5	
1 000116	13805000	equ25 move.b d0,0(a1,d5.w)	clear previous line's right side
1 00011A	5345	subq.w #1,d5	
1 00011C	51CCFFF8	dbra d4,equ25	
1 000120	51C9FFE2	dbra d1,equ23	
1 000124	4E5E	unlk a6	
1 000126	4E75	rts	
		end	

0 errors detected.

DirectionalFilter Directional average.

Address Object

Statement.

```

                                xdef   DirectionalFilter
00000001                        section 1

                                include macros.def           include macro definitions
00000001                        NOLIST
                                NOLIST

                                include global.def           include global symbol definitions
**                               Global.def - global symbol definitions.
*
*                               Copyright (C) 1986, CFA Technologies, Inc.

****                               Intensity level definitions.
00000000                        L0      equ    0
00000010                        L1      equ    16
00000020                        L2      equ    32
00000030                        L3      equ    48
00000040                        L4      equ    64
00000050                        L5      equ    80
00000060                        L6      equ    96
00000070                        L7      equ   112
00000080                        L8      equ   128
00000090                        L9      equ   144
000000A0                        L10     equ   160
000000B0                        L11     equ   176
000000C0                        L12     equ   192
000000D0                        L13     equ   208
000000E0                        L14     equ   224
000000FF                        L15     equ   255

****                               Useful constants.
00000009                        Yshift equ    9           ; log 2 of X and Y coordinate bounds
000001FF                        Border  equ   (1<<Yshift)-1 ; X and Y coordinate border

****                               Character constants.
00000020                        Space  equ    $20
00000007                        Bel    equ    'G'-$40
00000008                        BS     equ    'H'-$40
00000009                        Tab    equ    'I'-$40
0000000A                        LF     equ    'J'-$40
0000000C                        FF     equ    'L'-$40
0000000D                        CR     equ    'M'-$40
0000000E                        SO     equ    'N'-$40
0000000F                        SI     equ    'O'-$40
00000011                        Xon    equ    'Q'-$40

```

```

Address Object      Statement.
00000013 Xoff   equ   'S'-$40
00000018 Esc    equ   '['-$40
0000007F Del    equ   $7f
00000019 CtrlY  equ   'Y'-$40

*** Constants used to control LEDs

* Legal codes for ButtonLight (SwitchOff also good for FingerLight)

00000000 SwitchOff equ 0 ~
00000001 YesAndNo equ 1
00000002 Capture equ 2
00000003 SwitchTest equ 3

* Codes to control fluorescent lights

00000001 FluorRoll equ 1
00000002 FluorSlap equ 2

*** Assembly constants.

** Tunable parameters.

00000005 XGridLog equ 5 log2(slope x-grid size)
00000004 YGridLog equ 4 log2(slope y-grid size)
00000001 Step equ 1 step distance when determining slopes
000000FF BackFill equ LIS background fill value (white)

** - Derived constants.

00000020 XGridSize equ 1<<XGridLog size of x-grid to determine line slopes
00000010 YGridSize equ 1<<YGridLog size of y-grid to determine line slopes
00000010 XOffset equ XGridSize/2 x-displacement for offset slope grid
00000008 YOffset equ YGridSize/2 y-displacement for offset slope grid
0000000F LastXGrid equ Border/XGridsize index of last slope x-grid
0000001F LastYGrid equ Border/YGridsize index of last slope y-grid

***

** DirectionalFilter - Directional average to bitmap.
* Based on Pascal design by M. S. Ransoa.
* Implemented in 68000 assembler and modified to run
* without buffers by D. E. Germann.
*
```


Address Object

Statement.

```

*   entry   (a1.l) = address of input image screen buffer.
*           NOTE: there must be 2*(Border+1) bytes of free memory
*           in front of the input image screen buffer.
*
*   exit    (a1.l) = address of output image screen buffer.
*
*   uses    a - 1.
*           d - none.
*
*   calls   none.

```

```

                                VarBegin
00000000 +Voffset set      0
                                Var.l      ScreenOut,l
FFFFFFFC + nolist
                                Array2.l   GridTotal,-1,LastYGrid,-1,LastXGrid,4
FFFFDE0C + nolist
                                Array2.l   OffTotal,-1,LastYGrid,-1,LastXGrid,4
FFFFBAFC + nolist
                                Array2.b   Slopes,-1,LastYGrid,-1,LastXGrid,1
FFFFB78D + nolist
                                Array2.b   OffSlopes,-1,LastYGrid,-1,LastXGrid,1
FFFFB58C + nolist
                                VarEnd     DirRaa
FFFFB57A + nolist

```

DirectionalFilter

```

l 000000 4E56B57A link    a6,#DirRaa
l 000004 48E7FFBC movem.l a0/a2-a5/d0-d7,-(sp)  save registers
l 000008 2049     move.l  a1,a0                save input image address for later
l 00000A 2449     move.l  a1,a2
l 00000C 94FC0400 sub.w   #2*(Border+1),a2      compute address of output image
l 000010 2D4AFFFC move.l  a2,ScreenOut(a6)     save output image address

```

* Initialize.

```

l 000014 7000     moveq   #0,d0
l 000016 323C08C3 move.w  #((1+1+LastYGrid)*(1+1+LastXGrid)*4)-1,d1 longwords to clear
l 00001A 3401     move.w  d1,d2
l 00001C 43EEDCEC lea    GridTotal-(1*(1+1+LastXGrid)*(4*4))-(4*4)(a6),a1
l 000020 22C0     dir2   move.l  d0,(a1)+          GridTotal[*,*,*] := 0
l 000022 51C9FFFC dbra   d1,dir2
l 000026 43EEB9DC lea    OffTotal-(1*(1+1+LastXGrid)*(4*4))-(4*4)(a6),a1
l 00002A 22C0     dir3   move.l  d0,(a1)+          OffTotal[*,*,*] := 0
l 00002C 51CAFFFC dbra   d2,dir3

```

* Compute grid directional sums.

```

l 000030 7800     moveq   #0,d4                clear pixel register
l 000032 7401     moveq   #1,d2                y := 1
l 000034 2E02     dir4   move.l  d2,d7

```

Address Object	61	Statement.	62
1 000036 E847		asr.w #YGridLog,d7	GridY ← y div YGridSize
1 000038 3607		ifne LastXGrid-15	
1 00003A E947		move.w d7,d3	
1 00003C DE43		asl.w #4,d7	* 16
		add.w d3,d7	GridY * (1 + 1 + LastXGrid)
		endc	
		ifne LastXGrid-15	
		muls #(1+1+LastXGrid),d7	GridY * (1 + 1 + LastXGrid)
		endc	
1 00003E E987		asl.l #2+2,d7	[GridY, 0]
1 000040 47EED0C		lea GridTotal(a6),a3	
1 000044 D7C7		add.l d7,a3	addr(GridTotal[GridY, 0])
1 000046 7EF8		moveq #-YOffset,d7	
1 000048 DE82		add.l d2,d7	y - Yoffset
1 00004A E847		asr.w #YGridLog,d7	GridY2 := (y - YOffset) div YGridSize
		ifne LastXGrid-15	
1 00004C 3607		move.w d7,d3	
1 00004E E947		asl.w #4,d7	* 16
1 000050 DE43		add.w d3,d7	GridY2 * (1 + 1 + LastXGrid)
		endc	
		ifne LastXGrid-15	
		muls #(1+1+LastXGrid),d7	GridY2 * (1 + 1 + LastXGrid)
		endc	
1 000052 E987		asl.l #2+2,d7	[GridY2, 0]
1 000054 49EEBAFC		lea OffTotal(a5),a4	
1 000058 D9C7		add.l d7,a4	addr(OffTotal[GridY2, 0])
1 00005A 98FC0010		sub.w #4*4,a4	addr(OffTotal[GridY2, -1])
1 00005E 7E09		moveq #Yshift,d7	
1 000060 2602		move.l d2,d3	
1 000062 EFA3		asl.l d7,d3	convert y to coordinate offset
1 000064 2A48		move.l a0,a5	
1 000066 DBC3		add.l d3,a5	addr(ScreenIn[0, y])
1 000068 7200		moveq #0,d1	x := 0
1 00006A 7C20		moveq #XGridSize,d6	grid counter for GridTotal
1 00006C 7E10		moveq #XGridSize/2,d7	grid counter for OffTotal
1 00006E 1015	dir5	move.b (a5),d0	pixel := ScreenIn[x, y]
1 000070 182D0001		move.b 1(a5),d4	dot := ScreenIn[x+1, y]
1 000074 9840		sub.w d0,d4	dot - pixel
1 000076 5C02		bge.s dir6	
1 000078 4444		neg.w d4	abs(dot - pixel)
1 00007A D998	dir6	add.l d4,(a3)+	add to horizontal sum
1 00007C D99C		add.l d4,(a4)+	
1 00007E 182D0201		move.b 1+(Border+1)(a5),d4	dot := ScreenIn[x+1, y+1]
1 000082 9840		sub.w d0,d4	dot - pixel
1 000084 5C02		bge.s dir7	
1 000086 4444		neg.w d4	abs(dot - pixel)
1 000088 D998	dir7	add.l d4,(a3)+	add to positive slope sum

Address	Object	Statement.	
1 00008A	D99C	add.l d4,(a4)+	
1 00008C	182D0200	move.b Border+1(a5),d4	dot := ScreenIn[x, y+1]
1 000090	9840	sub.w d0,d4	dot - pixel
1 000092	6C02	bge.s dir8	
1 000094	4444	neg.w d4	abs(dot - pixel)
1 000096	D99B	dir8 add.l d4,(a3)+	add to vertical sum
1 000098	D99C	add.l d4,(a4)+	
1 00009A	182DFE01	move.b 1-(Border+1)(a5),d4	dot := ScreenIn[x+1, y-1]
1 00009E	9840	sub.w d0,d4	dot - pixel
1 0000A0	6C000004	bge dir9	
1 0000A4	4444	neg.w d4	abs(dot - pixel)
1 0000A6	D993	dir9 add.l d4,(a3)	add to negative slope sum
1 0000A8	D994	add.l d4,(a4)	
1 0000AA	96FC000C	sub.w #3*d4,a3	go back to start of array
1 0000AE	98FC000C	sub.w #3*d4,a4	
1 0000B2	5241	addq.w #Step,d1	x := x + Step
1 0000B4	528D	addq.l #Step,a5	advance screen pointer
1 0000B6	5346	subq.w #Step,d6	GTcounter := GTcounter - Step
1 0000B8	6E08	bgt.s dir9.1	if more pixels in this grid
1 0000BA	D6FC0010	add.w #4*d4,a3	go to next array entry
1 0000BE	DC7C0020	add.w #XGridSize,d6	update GTcounter
1 0000C2	5347	dir9.1 subq.w #Step,d7	GTcounter := GTcounter - Step
1 0000C4	6E08	bgt.s dir9.2	if more pixels in this grid
1 0000C6	D8FC0010	add.w #4*d4,a4	go to next array entry
1 0000CA	DE7C0020	add.w #XGridSize,d7	update OTcounter
1 0000CE	B27C01FE	dir9.2 cmp.w #Border-1,d1	
1 0000D2	6F9A	ble dir5	if x <= (Border - 1)
1 0000D4	5242	dir10 addq.w #Step,d2	y := y + Step
1 0000D6	B47C01FE	cmp.w #Border-1,d2	
1 0000DA	6F00FF58	ble dir4	if y <= (Border - 1)
* Determine line slopes.			
1 0000DE	43EEDCEC	dir11 - lea GridTotal-(1*(1+1+LastXGrid)*#(4*d4))-(1*(4*d4))(a6),a1	GT[-1,-1]
1 0000E2	45EEB9DC	lea OffTotal-(1*(1+1+LastXGrid)*#(4*d4))-(1*(4*d4))(a6),a2	OT[-1,-1]
1 0000E6	47EEB7AB	lea Slopes-(1*(1+1+LastXGrid))-1(a6),a3	Slopes[-1,-1]
1 0000EA	49EEB57A	lea OffSlopes-(1*(1+1+LastXGrid))-1(a6),a4	OffSlopes[-1,-1]
1 0000EE	7420	moveq #LastYGrid+1+1-1,d2	y := -1 to LastYGrid (d2 counts down)
1 0000F0	7210	dir12 moveq #LastXGrid+1+1-1,d1	x := -1 to LastXGrid (d1 counts down)
1 0000F2	2E19	dir13 move.l (a1)+,d3	min := GridTotal[y, x, Horizontal]
1 0000F4	7800	moveq #0*d4,d4	mindir := Horizontal
1 0000F6	2E19	move.l (a1)+,d7	next := GridTotal[y, x, PositiveSlope]
1 0000F8	8E83	cmp.l d3,d7	
1 0000FA	6C04	bge.s dir14	if next >= min
1 0000FC	2607	move.l d7,d3	min := next
1 0000FE	7804	moveq #1*d4,d4	mindir := PositiveSlope
1 000100	2E19	dir14 move.l (a1)+,d7	next := GridTotal[y, x, Vertical]
1 000102	8E83	cmp.l d3,d7	
1 000104	6C04	bge.s dir15	if next >= min
1 000106	2607	move.l d7,d3	min := next
1 000108	7808	moveq #2*d4,d4	mindir := Vertical
1 00010A	2E19	dir15 move.l (a1)+,d7	next := GridTotal[y, x, NegativeSlope]
1 00010C	8E83	cmp.l d3,d7	

Address	Object	Statement.	
1 00010E	6C02	bge.s dir16	if next >= min
1 000110	780C	moveq #3*4,d4	mindir := NegativeSlope
1 000112	16C4	dir16 move.b d4,(a3)+	Slopes[y, x] := mindir
1 000114	261A	move.l (a2)+,d3	min := OffTotal[y, x, Horizontal]
1 000116	7800	moveq #0*4,d4	mindir := Horizontal
1 000118	2E1A	move.l (a2)+,d7	next := OffTotal[y, x, PositiveSlope]
1 00011A	BE83	cmp.l d3,d7	
1 00011C	6C04	bge.s dir17	if next >= min
1 00011E	2607	move.l d7,d3	min := next
1 000120	7804	moveq #1*4,d4	mindir := PositiveSlope
1 000122	2E1A	dir17 move.l (a2)+,d7	next := OffTotal[y, x, Vertical]
1 000124	BE83	cmp.l d3,d7	
1 000126	6C04	bge.s dir18	if next >= min
1 000128	2607	move.l d7,d3	min := next
1 00012A	7808	moveq #2*4,d4	mindir := Vertical
1 00012C	2E1A	dir18 move.l (a2)+,d7	next := OffTotal[y, x, NegativeSlope]
1 00012E	BE83	cmp.l d3,d7	
1 000130	6C02	bge.s dir19	if next >= min
1 000132	780C	moveq #3*4,d4	mindir := NegativeSlope
1 000134	18C4	dir19 move.b d4,(a4)+	OffSlopes[y, x] := mindir
1 000136	51C9FFBA	dbra d1,dir13	do next x
1 00013A	51CAFFBA	dbra d2,dir12	do next y
		* Average image.	
1 00013E	226EFFFC	move.l ScreenOut(a6),a1	
1 000142	D1FC00001FF	add.l #Border,a0	set up for loop entry
1 000148	D3FC00001FF	add.l #Border,a1	
1 00014E	7400	moveq #0,d2	clear pixel register
1 000150	7201	moveq #1,d1	y := 1
1 000152	2801	dir20 move.l d1,d4	
1 000154	E844	asr.w #YGridLog,d4	GridY := y div YGridSize
		ifeq LastXGrid-15	
1 000156	3A04	move.w d4,d5	
1 000158	E944	asl.w #4,d4	* 16
1 00015A	D845	add.w d5,d4	GridY * (1+1+LastXGrid) ([GridY, 0])
		endc	
		ifne LastXGrid-15	
		muls #(1+1+LastXGrid),d4	GridY * (1+1+LastXGrid) ([GridY, 0])
		endc	
1 00015C	45EEB780	lea Slopes(a6),a2	
1 000160	D5C4	add.l d4,a2	addr(Slopes[GridY, 0])
1 000162	78F8	moveq #-YOffset,d4	
1 000164	D981	add.l d1,d4	y - Yoffset
1 000166	E844	asr.w #YGridLog,d4	GridY2 := (y - Yoffset) div YGridSize
		ifeq LastXGrid-15	
1 000168	3A04	move.w d4,d5	
1 00016A	E944	asl.w #4,d4	* 16
1 00016C	D845	add.w d5,d4	GridY2 * (1+1+LastXGrid) ([GridY2, 0])

Address Object	Statement.	
	endc	
	ifne LastXGrid-15	
	muls #(LastXGrid+1+1),d4	GridY2 * (1+1+LastXGrid) ([GridY2 0])
	endc	
1 00016E 47EEB58C	lea OffSlopes(a6),a3	
1 000172 D7C4	add.l d4,a3	addr(OffSlopes[GridY2, 0])
1 000174 534B	subq.w #1,a3	addr(OffSlopes[GridY2, -1])
1 000176 7001	moveq #1,d0	x := 1
1 000178 5488	addq.l #2,a0	point input screen pointer at next line
1 00017A 5489	addq.l #2,a1	point output screen pointer at next line
1 00017C 4BFA006A	lea SideComp(pc),a5	
1 000180 7E00	moveq #0,d7	
1 000182 1E1A	move.b (a2)+,d7	main grid slope for this grid
1 000184 2C357000	move.l 0(a5,d7.w),d6	main grid component offsets
1 000188 7820	moveq #XGridSize,d4	grid counter for GridSlopes
1 00018A 1E1B	move.b (a3)+,d7	offset grid slope for this grid
1 00018C 2E357000	move.l 0(a5,d7.w),d7	offset grid component offsets
1 000190 7A10	moveq #XGridSize/2,d5	grid counter for OffSlopes
1 000192 B743	dir21 eor.w d3,d3	sum := 0
1 000194 1618	move.b (a0)+,d3	
1 000196 D643	add.w d3,d3	
1 000198 D643	add.w d3,d3	sum := Screen[x, y] * 4
1 00019A 143060FF	move.b -(a0,d6.w),d2	
1 00019E D642	add.w d2,d3	add side one
1 0001A0 4846	swap d6	
1 0001A2 143060FF	move.b -(a0,d6.w),d2	
1 0001A6 D642	add.w d2,d3	add side two
1 0001A8 143070FF	move.b -(a0,d7.w),d2	
1 0001AC D642	add.w d2,d3	add side one
1 0001AE 4847	swap d7	
1 0001B0 143070FF	move.b -(a0,d7.w),d2	
1 0001B4 D642	add.w d2,d3	add side two
1 0001B6 5843	addq.w #8/2,d3	add in rounding factor
1 0001B8 E64B	lsr.w #3,d3	average := round(sum / 8)
1 0001BA 12C3	move.b d3,(a1)+	ScreenOut[x, y] := average
1 0001BC 5240	addq.w #1,d0	x := x + 1
1 0001BE 5344	subq.w #1,d4	GScouter := GScouter - 1
1 0001C0 6E08	bgt.s dir23.1	if more pixels in this grid
1 0001C2 181A	move.b (a2)+,d4	slope for next grid
1 0001C4 2C3B4022	move.l SideComp(pc,d4.w),d6	main grid component offsets
1 0001C8 7820	moveq #XGridSize,d4	
1 0001CA 5345	dir23.1 subq.w #1,d5	OScouter := OScouter - 1
1 0001CC 6E08	bgt.s dir23.2	if more pixels in this grid
1 0001CE 1A1B	move.b (a3)+,d5	slope for next grid
1 0001D0 2E3B5016	move.l SideComp(pc,d5.w),d7	offset grid component offsets
1 0001D4 7A20	moveq #XGridSize,d5	
1 0001D6 B07C01FE	dir23.2 cmp.w #Border-1,d0	
1 0001DA 6FB6	ble.s dir21	if x <= (Border - 1)
1 0001DC 5241	addq.w #1,d1	y := y + 1
1 0001DE B27C01FE	cmp.w #Border-1,d1	
1 0001E2 6F00FF5E	ble dir20	if y <= (Border - 1)

```

Address Object      Statement.
1 0001E6 6010      bra.s   dir30          clean-up borders and exit

** Side component offsets.
*

SideComp
1 0001E8 FFFF0001  dc.w   -1,1           horizontal
1 0001EC F0FF0201  dc.w   0-1-(Border+1),1+(Border+1)  positive slope
1 0001F0 FE000200  dc.w   -(Border+1),Border+1         vertical
1 0001F4 01FFFE01  dc.w   0-1+(Border+1),1-(Border+1)  negative slope

** Clear border areas that are garbage because directional
* filter doesn't operate on the whole image.

1 0001F8 203CFFFFFFF dir30  move.l  $(BackFill<<24)+(BackFill<<16)+(BackFill<<8)+BackFill,d0
1 0001FE 323C007F      move.w  $((Border+1)/4)-1,d1
1 000202 226EFFFFC      move.l  ScreenOut(a5),a1
1 000206 22C0          dir31  move.l  d0,(a1)+       clear upper raster line
1 000208 51C9FFFC      dbra   d1,dir31
1 00020C 323C007F      move.w  $((Border+1)/4)-1,d1
1 000210 226EFFFFC      move.l  ScreenOut(a6),a1
1 000214 03FC00040000  add.l  $((Border+1)*$((Border+1))),a1
1 00021A 2300          dir32  move.l  d0,-(a1)       clear lower raster line
1 00021C 51C9FFFC      dbra   d1,dir32
1 000220 226EFFFFC      move.l  ScreenOut(a6),a1
1 000224 323C01FF      move.w  #Border,d1
1 000228 1280          dir33  move.b  d0,(a1)       clear left side
1 00022A 134001FF      move.b  d0,Border(a1) clear right side
1 00022E D2FC0200      add.w  #Border+1,a1   position to next raster line
1 000232 51C9FFF4      dbra   d1,dir33
1 000236 4CDF30FF      movem.l (sp)+,a0/a2-a5/d0-d7  restore registers
1 00023A 226EFFFFC      move.l  ScreenOut(a6),a1  return output image address
1 00023E 4E5E          unlk   a6
1 000240 4E75          rts

end

```

0 errors detected.

Unhair - remove  from image.

```

Address Object      Statement.

xdef   Unhair

include macros.def  macro definitions
NOLIST
NOLIST

include global.def  global symbol definitions

```

00000001

Address Object

Statement.

```

** Global.def - global symbol definitions.
*
* Copyright (C) 1985, CFA Technologies, Inc.

```

```

*** Intensity level definitions.

```

```

00000000 L0 equ 0
00000010 L1 equ 16
00000020 L2 equ 32
00000030 L3 equ 48
00000040 L4 equ 64
00000050 L5 equ 80
00000060 L6 equ 96
00000070 L7 equ 112
00000080 L8 equ 128
00000090 L9 equ 144
000000A0 L10 equ 160
000000B0 L11 equ 176
000000C0 L12 equ 192
000000D0 L13 equ 208
000000E0 L14 equ 224
000000FF L15 equ 255

```

```

*** Useful constants.

```

```

00000009 Yshift equ 9 ; log 2 of X and Y coordinate bounds
000001FF Border equ (1<<Yshift)-1 ; X and Y coordinate border

```

```

*** Character constants.

```

```

00000020 Space equ $20
00000007 Bel equ '$40
00000008 BS equ '$40
00000009 Tab equ '$40
0000000A LF equ '$40
0000000C FF equ '$40
0000000D CR equ '$40
0000000E SO equ '$40
0000000F SI equ '$40
00000011 Xon equ '$40
00000012 Xoff equ '$40
0000001B Esc equ '$40
0000007F Del equ $7f
00000019 CtrlY equ '$40

```

```

*** Constants used to control LEDs

```

```

* Legal codes for ButtonLight (SwitchOff also good for FingerLight)

```

```

00000000 SwitchOff equ 0
00000001 YesAndNo equ 1
00000002 Capture equ 2
00000003 SwitchTest equ 3

```

```

* Codes to control fluorescent lights

```

```

Address Object      Statement.
00000001 FluorRoll equ 1
00000002 FluorSlap equ 2

include section.def section number definitions

**** Section definitions.

00000001 CodeSect equ 1 code and pc-relative constants
00000002 DataSect equ 2 read/write data area
00000003 RODataSect equ 3 read only data area

**** Assembly options.

00000000 FillRidges equ false fill in "holes" in ridges too

****

00000001 - section CodeSect

*** Unhair - remove hairs from image.
*
* Algorithm by G. M. Fishbine.
* Implemented in 68000 assembly language by D. E. Germann.
*
* Copyright (C) 1986, CFA Technologies, Inc.
*
* entry (a0 l) = screen buffer address.
* (d0.w) = hair width in dots.
* (d1.b) = black/white threshold.
*
* exit hairs removed from image
* optionally (assembly time), ridge "holes" filled in, too
*
* uses a - none.
* d - none
*
* calls none.

! 000000 48E7FF40 Unhair movem.l a1/d0-d7, -(sp)
! 000004 1E01 move.b d1,d7 put threshold into a safe register
! 000006 3200 move.w d0,d1
! 000008 D241 add.w d1,d1 2n
! 00000A 3401 move.w d1,d2
! 00000C D440 add.w d0,d2
! 00000E 5342 subq.w #1,d2 3n-1
! 000010 283C000001FF move.l #Border,d4 y := Border downto 0
! 000016 2C04 unhl move.l d4,d6
! 000018 7609 moveq #Yshift,d3
! 00001A E7A6 asl.l d3,d6 convert y-coord to screen offset
! 00001C 2248 move.l a0,a1
! 00001E D3C6 add.l d6,a1 addr(Screen[0, y])
! 000020 363C01FF move.w #Border,d3

```


Address	Object	Statement	
1 000024	9642	sub.w d2,d3	x := 0 to Border-(3n-1) (d3 counts down)
1 000026	BE11	unh2 cmp.b (a1),d7	
		ift FillRidges	
		+ IFNE FillRidges	
		bhi.s unh4	if Screen[x, y] is a dark pixel
		endc	
		iff FillRidges	
		+ IFEQ FillRidges	
1 000028	625A	bhi.s unh8	if Screen[x, y] is a dark pixel
		endc	
1 00002A	BE311000	cmp.b 0(a1,d1.w),d7	
1 00002E	6254	bhi.s unh8	if Screen[x+2n, y] is a dark pixel
1 000030	7C01	moveq #1,d6	i := 1
1 000032	8046	cmp.w d6,d0	
1 000034	6718	beq.s unh3.5	if n = 1, skip loops
1 000036	3A06	move.w d6,d5	
1 000038	DA41	add.w d1,d5	i + 2n
1 00003A	BE316000	unh3 cmp.b 0(a1,d6.w),d7	
1 00003E	6244	bhi.s unh8	if Screen[x+i, y] is a dark pixel
1 000040	BE315000	cmp.b 0(a1,d5.w),d7	
1 000044	623E	bhi.s unh8	if Screen[x+i+2n, y] is a dark pixel
1 000046	5246	addq.w #1,d6	i := i + 1
1 000048	5245	addq.w #1,d5	update i + 2n, too
1 00004A	BC40	cmp.w d0,d6	
1 00004C	6DEC	blt.s unh3	if i < n
1 00004E	7AFF	unh3.5 moveq #L15,d5	filler := L15
1 000050	6026	bra.s unh6	make inner pixels match outer pixels
1 000052	BE311000	unh4 cmp.b 0(a1,d1.w),d7	
1 000056	632C	bls.s unh8	if Screen[x+2n, y] is a light pixel
1 000058	7C01	moveq #1,d6	i := 1
1 00005A	B046	cmp.w d6,d0	
1 00005C	6718	beq.s unh5.5	if n = 1, skip loops
1 00005E	3A06	move.w d6,d5	
1 000060	DA41	add.w d1,d5	i + 2n
1 000062	BE316000	unh5 cmp.b 0(a1,d6.w),d7	
1 000066	631C	bls.s unh8	if Screen[x+i, y] is a light pixel
1 000068	BE315000	cmp.b 0(a1,d5.w),d7	
1 00006C	6316	bls.s unh8	if Screen[x+i+2n, y] is a light pixel
1 00006E	5246	addq.w #1,d6	i := i + 1
1 000070	5245	addq.w #1,d5	update i + 2n, too
1 000072	BC40	cmp.w d0,d6	
1 000074	6DEC	blt.s unh5	if i < n
1 000076	7A00	unh5.5 moveq #L0,d5	filler := L0
1 000078	3C00	unh6 move.w d0,d6	i := n
1 00007A	13856000	unh7 move.b d5,0(a1,d6.w)	Screen[x+i, y] := filler
1 00007E	5246	addq.w #1,d6	i := i + 1
1 000080	BC41	cmp.w d1,d6	
1 000082	6DF6	blt.s unh7	if i < 2n
1 000084	5289	unh8 addq.l #1,a1	x := x + 1
1 000086	51C8FF9E	dbra d3,unh2	do next x
1 00008A	51C8FF8A	dbra d4,unh1	do next y

```
! 00008E 4CDF02FF      moves.l (sp)+,a1/d0-d7
! 000092 4E75          rts
```

```
end
```

```
0 errors detected.
```

```
program FixCurvatureOffsetGen; { for assembly source }
```

```
const Vertical = false;
```

```
var I, Column: integer;
    Inp, Result: text;
    Offsets: array [0..511] of integer;
    Xold, Yold, X, Y, Min, Max: integer;
    Going: boolean;
    TrayName, FileName: string [201];
```

```
const Tab = ^I;
```

```
procedure XYMove(XZ, YZ, XN, YN: integer);
```

```
{ ACM Algorithm 162: X/Y move plotting }
```

```
var A, B, D, E, F, T, I, Move: integer;
    Xp, Yp: integer;
```

```
function Code(J: integer): integer;
begin
  if J = 15 then Code := 1
  else Code := J - ((J div 4) + 2);
end;
```

```
procedure Plot(Move: integer);
var Dir, Pixel, I: integer;
const OffsetX: array [0..7] of integer = ( 1, 1, 0,-1,-1,-1, 0, 1);
      OffsetY: array [0..7] of integer = ( 0, 1, 1, 1, 0,-1,-1,-1);
begin
  if Move <= 3 then Dir := 3 - Move
  else Dir := 11 - Move;
  Xp := Xp + OffsetX[Dir];
  Yp := Yp + OffsetY[Dir];
  if Vertical then begin
    Offsets[Yp] := Xp;
    if Xp < Min then Min := Xp;
  end
  else begin
    Offsets[Xp] := Yp;
    if Yp > Max then Max := Yp;
  end;
end;
```

```
begin { XYMove }
  Xp := XZ;
  Yp := YZ;
```



```

if (XZ <> XN) or (YZ <> YN) then begin
  A := XN - XZ;
  B := YN - YZ;
  D := A + B;
  T := B - A;
  I := 0;
  if B >= 0 then I := 1;
  if D >= 0 then I := I + 2;
  if T >= 0 then I := I + 2;
  if A >= 0 then I := B - I else I := I + 19;
  A := abs(A);
  B := abs(B);
  F := A + B;
  D := B - A;
  if D >= 0 then begin T := A; D := -D; end else T := B;
  E := 0;
  Move := Code(I-1);
  I := Code(I);
  repeat
    A := D + E;
    B := T + E + A;
    if B >= 0 then begin E := F - 2; Plot(I); end
    else begin E := E + T; F := F - 1; Plot(Move); end;
  until F <= 0;
end;
end;

```

```

begin
for I:=0 to 511 do Offsets[I] := 0;
Going := false;
write('Tray name: ');
readln(TrayName);
FileName := TrayName + '.cur';
assign(Inp,FileName);
reset(Inp);
while not eof(Inp) do begin
  readln(Inp,X,Y);
  if Going then XYMove(Xold,Yold,X,Y)
  else begin
    if Vertical then begin
      Offsets[Y] := X;
      Min := X;
    end
    else begin
      Offsets[X] := Y;
      Max := Y;
    end;
  end;
  Xold := X;
  Yold := Y;
  Going := true;
end;
for I:=0 to 511 do begin
  if Offsets[I] > 0 then begin
    if Vertical then
      Offsets[I] := Offsets[I] - Min
    else

```

```

Offsets[I] := Max - Offsets[I];
end;
end;
FileName := TrayName + '.inc';
assign(Result,FileName);
rewrite(Result);
writeln(Result,TrayName);
Column := 0;
for I:=0 to 511 do begin
  if Column = 0 then write(Result,Tab,'d',Tab);
  write(Result,Offsets[I]);
  Column := Column + 1;
  if (I = 511) or (Column = 10) then begin
    writeln(Result);
    Column := 0;
  end;
  else
    write(Result,',');
  end;
writeln(Result);
close(Result);
end

```

FixCurvature - ρ - act curvature in image.

Address Object

Statement.

```

                                xdef   FixCurvature

00000001                        section 1

                                include global.def~          global symbol definitions
**                               Global.def - global symbol definitions.
*
*                               Copyright (C) 1986, CFA Technologies, Inc.

                                **** Intensity level definitions.

00000000      L0      equ      0
00000010      L1      equ      16
00000020      L2      equ      32
00000030      L3      equ      48
00000040      L4      equ      64
00000050      L5      equ      80
00000060      L6      equ      96
00000070      L7      equ     112
00000080      L8      equ     128
00000090      L9      equ     144
000000A0      L10     equ     160
000000B0      L11     equ     176
000000C0      L12     equ     192
000000D0      L13     equ     208

```



```

Address Object      Statement.
000000E0          L14    equ    224
000000FF          L15    equ    255

**** Useful constants.

00000009          Yshift equ    9          ; log 2 of X and Y coordinate bounds
000001FF          Border equ    (1<<Yshift)-1 ; X and Y coordinate border

**** Character constants.

00000020          Space equ    $20
00000007          Bel    equ    'G'-$40
00000008          BS     equ    'H'-$40
00000009          Tab    equ    'I'-$40
0000000A          LF     equ    'J'-$40
0000000C          FF     equ    'L'-$40
0000000D          CR     equ    'M'-$40
0000000E          SD     equ    'N'-$40
0000000F          SI     equ    'O'-$40
00000011          Xon   equ    'Q'-$40
00000013          Xoff  equ    'S'-$40
0000001B          Esc   equ    'U'-$40
0000007F          Del   equ    $7f
00000019          CtrlY equ    'Y'-$40

**** Constants used to control LEDs

* Legal codes for ButtonLight (SwitchOff also good for FingerLight)

00000000          SwitchOff equ    0
00000001          YesAndNo equ    1
00000002          Capture  equ    2
00000003          SwitchTest equ    3

* Codes to control fluorescent lights

00000001          FluorRoll equ    1
00000002          FluorSlap equ    2

**** Assembly constants

000000FF          Background equ    L15          background fill value

****
* FixCurvature - correct curvature in image.
* Based on Pascal implementation by M. S. Ransom.
* Converted to 68000 assembler by D. E. Germann.
*
* Copyright (C) 1986, CFA Technologies, Inc.
*
* entry (a5.l) = screen image address.

```

```

Address Object      Statement.
*                  (d0.w) = tray number.
*
*      exit      image corrected.
*
*      uses      a - none.
*                  d - none.
*
*      calls     none.

FixCurvature
1 000000 B07C0005      cmp.w   #4+1,d0
1 000004 6700005C      beq     fix30          if slap prints, skip decurve
1 000008 48E7E7A0      movem.l a0/a2/d0-d2/d5-d7,-(sp) save registers
1 00000C 45FA0056      lea    Offsets(pc),a2  offset pointer table address
1 000010 E540          asl.w  #2,d0          convert tray number to table offset
1 000012 247200FC      move.l -(a2,d0.w),a2  get table address for this tray

*      if desired, this is the place for a test for horiz/vert decurve.
*      Horizontal decurve.

1 000016 D5FC0000400      fix10  add.l  #(Border+1)*2,a2  move past end of table
1 00001C 2E3C0000200      move.l #1<<Yshift,d7   y-increment
1 000022 7C09          moveq  #Yshift,d6
1 000024 7AFF          moveq  #Background,d5  fill value for end of lines
1 000026 303C01FF      move.w #Border,d0      x := Border downto 0
1 00002A 7400          fix11  moveq  #0,d2
1 00002C 3422          move.w -(a2),d2       off := Offsets[x]
1 00002E 6F2A          ble.s  fix14          if not correcting this column
1 000030 323C01FF      move.w #Border,d1
1 000034 9242          sub.w  d2,d1          y := Border downto off
1 000036 207C0003FE00   move.l #Border<<Yshift,a0
1 00003C D1CD          add.l  a5,a0          Screen[0, Border]
1 00003E D0C0          add.w  d0,a0          Screen[x, Border]
1 000040 EDA2          asl.l  d6,d2          convert offset to y-coordinate address
1 000042 4482          neg.l  d2             generate -offset value
1 000044 10B02800      fix12  move.b 0(a0,d2.l),(a0)  Screen[x, y] := Screen[x, y-off]
1 000048 91C7          sub.l  d7,a0          y := y - 1
1 00004A 51C9FFF8      dbra  d1,fix12       if more pixels to move in this column
1 00004E 3412          move.w (a2),d2       off := Offsets[x]
1 000050 5342          subq.w #1,d2         i := off-1 downto 0
1 000052 10B5          fix13  move.b d5,(a0)       clear pixel
1 000054 91C7          sub.l  d7,a0          y := y - 1
1 000056 51CAFFFA      dbra  d2,fix13       if more pixels to clear in this column
1 00005A 51C8FFCE      fix14  dbra  d0,fix11       if more columns to decurve
1 00005E 4CDF05E7      fix20  movem.l (sp)+,a0/a2/d0-d2/d5-d7 restore registers
1 000062 4E75          fix30  rts

1 000064 000000740000  Offsets dc.l  Curve1,Curve2,Curve3,Curve4
          047400000874
          00000C74

nolist

end

```

0 errors detected.


```

program ChangeXConstantGen; ( for assembler source )
const Tab = 'I';
      Border = 511;
var I, Column, tray, MeetPoint: integ;
      Numerator, Denominator, LeftEdge, RightEdge: integer;
      Result: text;
      X, OldX, OldMiddle, NewMiddle: integer;
      Offsets: array [0..511] of integer;
      Answer: char;
      Linear, AlignEdge, Shrinking: boolean;

procedure GenerateOffsets;
var I, OldX, Y, NewX, PreviousOldX, Xincrement, Alignment: integer;
      Going: boolean;
      CoordFile: text;
      FileName: string [80];

      procedure XYMove(XZ, YZ, XN, YN: integer);

      ( ACM Algorithm 162: X/Y move plotting )

      var A, B, D, E, F, T, I, Move: integer;
            Xp, Yp: integer;

      function Code(J: integer): integer;
      begin
        if J = 15 then Code := 1
        else Code := J - ((J div 4) * 2);
      end;

      procedure Plot(Move: integer);
      var Dir, Pixel, I: integer;
      const OffsetX: array [0..7] of integer = ( 1, 1, 0, -1, -1, -1, 0, 1);
            OffsetY: array [0..7] of integer = ( 0, 1, 1, 1, 0, -1, -1, -1);
      begin
        if Move <= 3 then Dir := 3 - Move
        else Dir := 11 - Move;
        Xp := Xp + OffsetX[Dir];
        Yp := Yp + OffsetY[Dir];
        if (Yp >= 0) and (Yp <= Border) then
          Offsets[Yp] := Xp;
      end;

      begin ( XYMove )
        Xp := XZ;
        Yp := YZ;
        if (XZ <> XN) or (YZ <> YN) then begin
          A := XN - XZ;
          B := YN - YZ;
          D := A + B;
          T := B - A;
          I := 0;
          if B >= 0 then I := 2;
          if D >= 0 then I := I + 2;
          if T >= 0 then I := I + 2;
          if A <= 0 then I := 8 - I else I := I + 16;
          A := abs(A);

```

```

    E := abs(B);
    F := A + B;
    D := B - A;
    if D >= 0 then begin T := A; D := -D; end else T := B;
    E := 0;
    Move := Code(I-1);
    I := Code(I);
    repeat
      A := D + E;
      B := T + E + A;
      if B >= 0 then begin E := A; F := F - 2; Plot(I); end
      else begin E := E + T; F := F - 1; Plot(Move); end;
    until F <= 0;
  end;
end;

begin ( GenerateOffsets )
  write('Enter X increment, in dots: ');
  readln(Xincrement);
  write('Enter coordinate file name: ');
  readln(FileName);
  assign(CoordFile,FileName);
  reset(CoordFile);
  for I:=0 to 511 do Offsets[I] := -1;
  Going := false;
  NewX := 0;
  while not eof(CoordFile) do begin
    readln(CoordFile,OldX,Y);
    if Going then begin
      XYMove(PreviousOldX,NewX,OldX,NewX+Xincrement);
      NewX := NewX + Xincrement;
    end
    else begin
      Offsets[NewX] := OldX;
      LeftEdge := OldX;
    end;
    PreviousOldX := OldX;
    Going := true;
  end;
  close(CoordFile);
  if NewX > Border then NewX := Border;
  Shrinking := (NewX < (Offsets[NewX] - LeftEdge));
  if not AlignEdge then begin
    I := 0;
    while (I < NewX) and (Offsets[I] < OldMiddle) do I := I + 1;
    if ((I = 0) and (Offsets[I] > OldMiddle)) or
      (Offsets[I] < OldMiddle) then
      begin
        writeln('Old middle is outside picture bounds. ');
        Alignment := 0;
      end
    else Alignment := NewMiddle - I;
    if Alignment >= 0 then begin
      for I:=NewX downto 0 do begin
        Offsets[I+Alignment] := Offsets[I];
      end;
    end;
  end;
end;

```



```

    for I:=Alignment-1 downto 0 do
        Offsets[I] := -1;
    end
else begin
    for I:=-Alignment to NewX do begin
        Offsets[I+Alignment] := Offsets[I];
    end;
    for I:=NewX+Alignment+1 to NewX do
        Offsets[I] := -1;
    end;
end;
end;
end; ( GenerateOffsets )

begin
    assign(Result, 'changex.def');
    rewrite(Result);
    writeln(Result);
    writeln(Result, 'Shrinking', Tab, 'equ', Tab, '-4', Tab,
        'offset of shrink or expand flag');
    writeln(Result, 'MeetPoint', Tab, 'equ', Tab, '-2', Tab, 'offset of MeetPoint');
    close(Result);
    assign(Result, 'changex.inc');
    rewrite(Result);
    for tray := 1 to 5 do begin
        writeln('Tray ', tray:1, ': ');
        write('Linear or Non-linear change? ');
        readln(Answer);
        Linear := ((Answer = 'L') or (Answer = '1'));
        write('Align on left edge or middle? ');
        readln(Answer);
        AlignEdge := ((Answer = '1') or (Answer = 'L'));
        if not AlignEdge then begin
            write('Enter old middle X coordinate: ');
            readln(OldMiddle);
            write('Enter new middle X coordinate: ');
            readln(NewMiddle);
        end;
        if not Linear then GenerateOffsets
        else begin
            write('Enter ratio numerator and denominator: ');
            readln(Numerator, Denominator);
            Shrinking := (Numerator < Denominator);
            write('Enter Left and Right edge coordinates: ');
            readln(LeftEdge, RightEdge);
            if AlignEdge then begin
                for X:=0 to Border do begin
                    OldX := round(((X+0.0) * Denominator / Numerator) + LeftEdge);
                    if OldX < LeftEdge then OldX := -1;
                    if OldX > RightEdge then OldX := -1;
                    Offsets[X] := OldX;
                end;
            end
        else begin
            for X:=0 to Border do begin
                OldX := round((((X-NewMiddle)+0.0) * Denominator) / Numerator)

```

```

        + OldMiddle);
    if OldX < LeftEdge then OldX := -1;
    if OldX > RightEdge then OldX := -1;
    Offsets[X] := OldX;
end;
end;
end;
X := 0;
while (X < Border) and (X <> Offsets[X]) do begin
    if Offsets[X] >= 0 then begin
        if (Shrinking and (X > Offsets[X])) or
            ((not Shrinking) and (X < Offsets[X])) then
            MeetPoint := Border
        else
            MeetPoint := -1;
        end;
        X := X + 1;
    end;
if X = Offsets[X] then MeetPoint := X;

writeln(Result);
writeln(Result, '#', Tab, 'Tray ', tray:1);
writeln(Result);
if Shrinking then
    writeln(Result, Tab, 'dc.w', Tab, '$ff', Tab, 'shrinking')
else
    writeln(Result, Tab, 'dc.w', Tab, '0', Tab, 'not shrinking');
writeln(Result, Tab, 'dc.w', Tab, MeetPoint);
writeln(Result, 'Off', tray:1);
    Column := 0;
    for I:=0 to Border do begin
        if Column = 0 then write(Result, ' ', 'dc.w', Tab);
        write(Result, Offsets[I]);
        Column := Column + 1;
        if (I = Border) or (Column >= 10) then begin
            writeln(Result);
            Column := 0;
        end
        else
            write(Result, ', ');
        end;
    writeln(Result);
end;
writeln(Result);
writeln(Result, 'Offsets');
for tray := 1 to 5 do
    writeln(Result, Tab, 'dc.l', Tab, 'Off', tray:1);
close(Result);
end.

```


ChangeX - change in X direction.

Address Object

Statement.

```

                                xdef   ChangeX

00000001      section 1

                                include global.def      global symbol definitions
** Global.def - global symbol definitions.
*
* Copyright (C) 1986, CFA Technologies, Inc.

**** Intensity level definitions.

00000000      L0      equ      0
00000010      L1      equ      16
00000020      L2      equ      32
00000030      L3      equ      48
00000040      L4      equ      64
00000050      L5      equ      80
00000060      L6      equ      96
00000070      L7      equ     112
00000080      L8      equ     128
00000090      L9      equ     144
000000A0      L10     equ     160
000000B0      L11     equ     176
000000C0      L12     equ     192
000000D0      L13     equ     208
000000E0      L14     equ     224
000000FF      L15     equ     255

**** Useful constants.

00000009      Yshift equ      9      ; log 2 of X and Y coordinate bounds
000001FF      Border equ     (1<<Yshift)-1 ; X and Y coordinate border

**** Character constants.

00000020      Space  equ     $20
00000007      Bel    equ     'G'-$40
00000008      BS     equ     'H'-$40
00000009      Tab    equ     'I'-$40
0000000A      LF     equ     'J'-$40
0000000C      FF     equ     'L'-$40
0000000D      CR     equ     'M'-$40
0000000E      SO     equ     'N'-$40
0000000F      SI     equ     'O'-$40
00000011      Xon    equ     'Q'-$40
00000013      Xoff   equ     'S'-$40
0000001B      Esc    equ     '['-$40

```

Address Object
0000007F
00000019

Statement.
Del equ \$7f
CtrlY equ 'Y'-\$40

*** Constants used to control LEDs

* Legal codes for ButtonLight (SwitchOff also good for FingerLight)

00000000 SwitchOff equ 0
00000001 YesAndNo equ 1
00000002 Capture equ 2
00000003 SwitchTest equ 3

* Codes to control fluorescent lights

00000001 FluorRoll equ 1
00000002 FluorSlap equ 2

include changex.def changex symbol definitions

FFFFFFFFC Shrinking equ -4 offset of shrink or expand flag
FFFFFFFE MeetPoint equ -2 offset of MeetPoint

*** Assembly constants.

000000FF Background equ L15 background fill value

*** ChangeX - change image in X direction.
Based on Pascal implementation by M. S. Ransom.
Converted to 68000 assembler by D. E. Geruann.

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entry (a0.l) = screen image address.
(d0.w) = tray number.

exit image corrected.

uses a - none.
d - none.

calls move.

! 000000 48E7FE38 ChangeX movem.l a2-a4/d0-d6, -(sp) save registers
! 000004 45FA14A4 lea Offsets(pc), a2 offset pointer table address
! 000008 E540 asl.w #2, d0 convert tray number to table offset
! 00000A 247200FC move.l -4(a2, d0.w), a2 get table address for this tray
! 00000E 4A6AFFFC tst.w Shrinking(a2)

Address	Object	Statement.	
1 000012	6722	beq.s chx2	if expanding image
1 000014	302AFFFE	move.w MeetPoint(a2),d0	initial x := MeetPoint
1 000018	7200	moveq #0,d1	final x := 0
1 00001A	74FF	moveq #-1,d2	count down
1 00001C	8041	cmp.w d1,d0	
1 00001E	6D02	blt.s chx1	if nothing to do on this side
1 000020	613A	bsr.s move	compress left half of image
1 000022	302AFFFE	chx1 move.w MeetPoint(a2),d0	
1 000026	5240	addq.w #1,d0	initial x := MeetPoint+1
1 000028	323C01FF	move.w #Border,d1	final x := Border
1 00002C	7401	moveq #1,d2	count up
1 00002E	8041	cmp.w d1,d0	
1 000030	6E24	bgt.s chx4	if nothing to do on this side
1 000032	6128	bsr.s move	compress right half of image
1 000034	6020	bra.s chx4	
1 000036	7000	chx2 moveq #0,d0	initial x := 0
1 000038	322AFFFE	move.w MeetPoint(a2),d1	final x := MeetPoint
1 00003C	7401	moveq #1,d2	count up
1 00003E	8041	cmp.w d1,d0	
1 000040	6E02	bgt.s chx3	if nothing to do on this side
1 000042	6118	bsr.s move	expand left half of image
1 000044	303C01FF	chx3 move.w #Border,d0	initial x := Border
1 000048	322AFFFE	move.w MeetPoint(a2),d1	
1 00004C	5241	addq.w #1,d1	final x := MeetPoint+1
1 00004E	74FF	moveq #-1,d2	count down
1 000050	8041	cmp.w d1,d0	
1 000052	6D02	blt.s chx4	if nothing to do on this side
1 000054	6106	bsr.s move	expand right half of image
1 000055	4CDF1C7F	chx4 move.l (sp)+,a2-a4/d0-d6	restore registers
1 00005A	4E75	rts	
** move - expand or compress portion of image.			
* * * entry (a0.l) = screen address. * (a2.l) = offset table base address. * (d0.w) = initial x. * (d1.w) = final x. * (d2.w) = x increment (+/- 1). * * exit screen portion expanded or compressed * * uses a - 3, 4. * d - 0, 1, 3, 5, 6. * * calls none.			
1 00005C	D242	move add.w d2,d1	final value + increment
1 00005E	287C00000200	move.l #1<<Yshift,a4	y increment
1 000064	7AFF	moveq #Background,d5	preload background value
1 000066	3C3C01FF	movl move.w #Border,d6	y := 0 to Border (d6 counts down)
1 00006A	2648	move.l a0,a3	Screen[0, y]

Address	Object	Statement.	
1 00006C	3600	move.w d0,d3	
1 00006E	D643	add.w d3,d3	
1 000070	36323000	move.w 0(a2,d3.w),d3	OldX := Offset[x]
1 000074	6B14	bmi.s mov4	if this column is to be cleared
1 000076	17B330000000	mov2 move.b 0(a3,d3.w),0(a3,d0.w)	Screen[x, y] := Screen[OldX, y]
1 00007C	07CC	add.l a4,a3	y := y + 1
1 00007E	51CEFFF6	dbra d6,mov2	if more pixels to move in this column
1 000082	D042	mov3 add.w d2,d0	x := x + increment
1 000084	B041	cmp.w d1,d0	
1 000086	66DE	bne.s mov1	if more columns to process
1 000088	4E75	rts	
1 00008A	17850000	mov4 move.b d5,0(a3,d0.w)	Screen[x, y] := Background
1 00008E	D7CC	add.l a4,a3	y := y + 1
1 000090	51CEFFF8	dbra d6,mov4	if more pixels to clear in this column
1 000094	60EC	bra.s mov3	

nolist

end

0 errors detected.

```

program ChangeYConstantGen; { for assembler source }
const Tab = ^I;
      Border = 511;
var I, Column, tray: integer;
      Result: text;
      Y, OldY, MeetPoint: integer;
      ExpansionFactor: real;
      Numerator, Denominator, OldMiddle, NewMiddle, TopEdge, BottomEdge: integer;
      Offsets: array [0..511] of integer;
      Answer: char;
begin
  write('Expansion coefficient: ');
  readln(ExpansionFactor);
  assign(Result, 'changey.def');
  rewrite(Result);
  writeln(Result, 'Numerator', Tab, 'equ', Tab, '-6', Tab, 'offset of Numerator');
  writeln(Result, 'Denominator', Tab, 'equ', Tab, '-4', Tab, 'offset of Denominator');
  writeln(Result, 'MeetPoint', Tab, 'equ', Tab, '-2', Tab, 'offset of MeetPoint');
  close(Result);
  assign(Result, 'changey.inc');
  rewrite(Result);
  for tray := 1 to 5 do begin
    write('Numerator and denominator for tray ', tray, ': ');
    readln(Numerator, Denominator);
    Numerator := round(Numerator * ExpansionFactor);
    write('Enter Top and Bottom edge coordinates: ');
  end

```



```

readln(TopEdge, BottomEdge);
write('Align on top edge or middle? ');
readln(Answer);
if (Answer = 't') or (Answer = 'T') then begin
  for Y:=0 to Border do begin
    OldY := round(((Y+0.0) * Denominator / Numerator) + TopEdge);
    if OldY < TopEdge then OldY := -1;
    if OldY > BottomEdge then OldY := -1;
    Offsets[Y] := OldY;
  end;
  if (Numerator-Denominator) > 0 then begin
    if ((TopEdge+0.0)*Numerator) > ((Border+0.0)*(Numerator-Denominator))
      then MeetPoint := Border
    else if TopEdge < 0 then MeetPoint := -1
    else MeetPoint :=
      round((TopEdge+0.0) * Numerator / (Numerator-Denominator));
  end
  else if (Numerator-Denominator) < 0 then begin
    if ((TopEdge+0.0)*Numerator) < ((Border+0.0)*(Numerator-Denominator))
      then MeetPoint := Border
    else if TopEdge > 0 then MeetPoint := -1
    else MeetPoint :=
      round((TopEdge+0.0) * Numerator / (Numerator-Denominator));
  end
  else begin
    if TopEdge >= 0 then MeetPoint := Border
    else MeetPoint := -1;
  end;
end
else begin
  write('Enter old middle Y coordinate: ');
  readln(OldMiddle);
  write('Enter new middle Y coordinate: ');
  readln(NewMiddle);
  for Y:=0 to Border do begin
    OldY := round((((Y-NewMiddle)+0.0) * Denominator / Numerator)
      + OldMiddle);
    if OldY < TopEdge then OldY := -1;
    if OldY > BottomEdge then OldY := -1;
    Offsets[Y] := OldY;
  end;
  if (Numerator-Denominator) > 0 then begin
    if ((OldMiddle+0.0)*Numerator - (NewMiddle+0.0)*Denominator >
      ((Border+0.0)*(Numerator-Denominator))
      then MeetPoint := Border
    else if ((OldMiddle+0.0)*Numerator) < ((NewMiddle+0.0)*Denominator)
      then MeetPoint := -1
    else MeetPoint :=
      round( ((OldMiddle+0.0)*Numerator - (NewMiddle+0.0)*Denominator) /
        (Numerator - Denominator) );
  end
  else if (Numerator-Denominator) < 0 then begin
    if ((OldMiddle+0.0)*Numerator - (NewMiddle+0.0)*Denominator) <
      ((Border+0.0)*(Numerator-Denominator))
      then MeetPoint := Border
    else if ((OldMiddle+0.0)*Numerator) > ((NewMiddle+0.0)*Denominator)
      then MeetPoint := -1
  end;
end;

```

```

else MeetPoint :=
  round( ((OldMiddle+0.0)*Numerator - (NewMiddle+0.0)*Denominator) /
    (Numerator - Denominator) );
end
else begin
  if NewMiddle > OldMiddle then MeetPoint := -1
  else MeetPoint := Border;
end;
end;
if MeetPoint < 0 then MeetPoint := -1;
if MeetPoint > Border then MeetPoint := Border;
writeln(Result);
writeln(Result, '#', Tab, 'Tray ', tray:1, ': ');
writeln(Result);
writeln(Result, Tab, 'dc.w', Tab, Numerator, ', ', Denominator);
writeln(Result, Tab, 'dc.w', Tab, MeetPoint);
writeln(Result, 'Off', tray:1);
Column := 0;
for I:=0 to Border do begin
  if Column = 0 then write(Result, Tab, 'dc.w', Tab);
  write(Result, Offsets[I]);
  Column := Column + 1;
  if (I = Border) or (Column >= 10) then begin
    writeln(Result);
    Column := 0;
  end
  else
    write(Result, ', ');
  end;
  writeln(Result);
end;
writeln(Result);
writeln(Result, 'Offsets');
for tray := 1 to 5 do
  writeln(Result, Tab, 'dc.l', Tab, 'Off', tray:1);
close(Result);
end.

```

ChangeY - change page in Y direction

Address Object

Statement.

xdef ChangeY

00000001

section 1

include global.def ~ global symbol definitions

Global.def - global symbol definitions.

#

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Intensity level definitions.

00000000

L0 equ 0


```

00000010 L1 equ 16
00000020 L2 equ 32
00000030 L3 equ 48
00000040 L4 equ 64
00000050 L5 equ 80
00000060 L6 equ 96
00000070 L7 equ 112
00000080 L8 equ 128
00000090 L9 equ 144
000000A0 L10 equ 160
000000B0 L11 equ 176
000000C0 L12 equ 192
000000D0 L13 equ 208
000000E0 L14 equ 224
000000FF L15 equ 255

```

```

*** Useful constants.

```

```

00000009 Yshift equ 9 ; log 2 of X and Y coordinate bounds
000001FF Border equ (1<<Yshift)-1 ; X and Y coordinate border

```

```

*** Character constants.

```

```

00000020 Space equ $20
00000007 Bel equ 'G'-$40
00000008 BS equ 'H'-$40
00000009 Tab equ 'I'-$40
0000000A LF equ 'J'-$40
0000000C FF equ 'L'-$40
0000000D CR equ 'M'-$40
0000000E SO equ 'N'-$40
0000000F SI equ 'O'-$40
00000011 Xon equ 'Q'-$40
00000013 Xoff equ 'S'-$40
0000001B Esc equ 'T'-$40
0000007F Del equ $7f
00000019 CtrlY equ 'Y'-$40

```

```

*** Constants used to control LEDs

```

```

* Legal codes for ButtonLight (SwitchOff also good for FingerLight)

```

```

00000000 SwitchOff equ 0
00000001 YesAndNo equ 1
00000002 Capture equ 2
00000003 SwitchTest equ 3

```

```

* Codes to control fluorescent lights

```

```

00000001 FluorRoll equ 1
00000002 FluorSlap equ 2

```

```

include changey def changey symbol definitions
FFFFFFFFA Numerator equ -6 offset of Numerator
FFFFFFFFC Denominator equ -4 offset of Denominator
FFFFFFFFE MeetPoint equ -2 offset of MeetPoint

```

```
*** Assembly constants.
```

```
FFFFFFFF Background equ $FFFFFFFF background fill value
```

```
*** ChangeY - change image in Y direction.
* Based on Pascal implementation by M. S. Ranson.
* Converted to 68000 assembler by D. E. Germann.
*
* Copyright (C) 1986, CFA Technologies, Inc.
*
* entry (a0.l) = screen image address.
*       (d0.w) = tray number.
*
* exit  image corrected.
*
* uses  a - none.
*       d - none.
*
* calls move.
```

Address	Object	Statement.	
1 000000	48E7FE38	ChangeY movem.l a2-a4/d0-d6, -(sp)	save registers
1 000004	45FA14B4	lea Offsets(pc), a2	offset pointer table address
1 000008	E540	asl.w #2, d0	convert tray number to table offset
1 00000A	247200FC	move.l -4(a2, d0.w), a2	get table address for this tray
1 00000E	3C2AFFFA	move.w Numerator(a2), d6	
1 000012	BC6AFFFC	cmp.w Denominator(a2), d6	
1 000016	6C22	bge.s chy2	if expanding image
1 000018	302AFFFE	move.w MeetPoint(a2), d0	initial y := MeetPoint
1 00001C	7200	moveq #0, d1	final y := 0
1 00001E	74FF	moveq #-1, d2	count down
1 000020	8041	cmp.w d1, d0	
1 000022	6D02	blt.s chy1	if nothing to do on this side
1 000024	613A	bsr.s move	compress top half of image
1 000026	302AFFFE	chy1 move.w MeetPoint(a2), d0	
1 00002A	5240	addq.w #1, d0	initial y := MeetPoint+1
1 00002C	323C01FF	move.w #Border, d1	final y := Border
1 000030	7401	moveq #1, d2	count up
1 000032	8041	cmp.w d1, d0	
1 000034	6E24	bgt.s chy4	if nothing to do on this side
1 000036	6128	bsr.s move	compress bottom half of image
1 000038	6020	bra.s chy4	
1 00003A	7000	chy2 moveq #0, d0	initial y := 0
1 00003C	322AFFFE	move.w MeetPoint(a2), d1	final y := MeetPoint
1 000040	7401	moveq #1, d2	count up
1 000042	8041	cmp.w d1, d0	
1 000044	5E02	bgt.s chy3	if nothing to do on this side
1 000046	6118	bsr.s move	expand top half of image
1 000048	303C01FF	chy3 move.w #Border, d0	initial y := Border
1 00004C	322AFFFE	move.w MeetPoint(a2), d1	
1 000050	5241	addq.w #1, d1	final y := MeetPoint+1
1 000052	74FF	moveq #-1, d2	count down
1 000054	8041	cmp.w d1, d0	

Bitmap - convert gray-scale image to b&w bitmap

```

Address Object      Statement.

                                xdef   Bitmap

00000001           section 1

                                include global.def           include global symbol definitions
** Global.def - global symbol definitions.
*
* Copyright (C) 1986, CFA Technologies, Inc.

*** Intensity level definitions.

00000000          L0      equ    0
00000010          L1      equ    16
00000020          L2      equ    32
00000030          L3      equ    48
00000040          L4      equ    64
00000050          L5      equ    80
00000060          L6      equ    96
00000070          L7      equ   112
00000080          L8      equ   128
00000090          L9      equ   144
000000A0          L10     equ   160
000000B0          L11     equ   176
000000C0          L12     equ   192
000000D0          L13     equ   208
000000E0          L14     equ   224
000000FF          L15     equ   255

*** Useful constants.

00000009          Yshift  equ    9      ; log 2 of X and Y coordinate bounds
000001FF          Border  equ   (1<<Yshift)-1 ; X and Y coordinate border

*** Character constants.

00000020          Space   equ    $20
00000007          Bel     equ    'G'-$40
00000008          BS     equ    'H'-$40
00000009          Tab    equ    'I'-$40
0000000A          LF     equ    'J'-$40
0000000C          FF     equ    'L'-$40
0000000D          CR     equ    'M'-$40
0000000E          SO     equ    'N'-$40
0000000F          SI     equ    'O'-$40
00000011          Xon    equ    'Q'-$40
00000012          Xoff   equ    'S'-$40
00000012          Esc    equ    'C'-$40
0000007F          Del    equ    $7f

```



```

Address Object      Statement.
00000019          CtrlY    equ    'Y'-$40

*** Constants used to control LEDs

# Legal codes for ButtonLight (SwitchOff also good for FingerLight)

00000000          SwitchOff  equ    0
00000001          YesAndNo  equ    1
00000002          Capture   equ    2
00000003          SwitchTest equ    3

# Codes to control fluorescent lights

00000001          FluorRoll  equ    1
00000002          FluorSlap  equ    2

00000040          BitBytes   equ    (Border+1)/8    number of bytes/line in bitmap image

*** Bitmap - convert grey-scale image to b&w bitmap.
# Implemented in 68000 assembler by D. E. Germann.
#
# Copyright (C) 1986, CFA Technologies, Inc.
#
# entry (a1.l) = input screen image address, 512 x 512 x 8.
#       (a2.l) = output bitmap address, 512 x 512 x 1, packed.
#       (d0.b) = black/white threshold.
#
# exit  image packed.
#
# uses  a - none
#       d - none.
#
# calls none.

1 000000 48E7F760  Bitmap movem.l a1-a2/d0-d3/d5-d7,-(sp) save registers
1 000004 1600      move.b  d0,d3
1 000006 7CFF      moveq  #-1,d6          initialize bit accumulator
1 000008 3E3C8000    move.w  #1<<((16-1)),d7 bit counter
1 00000C 7AFF      moveq  #-1,d5          initialize bit mask
1 00000E 343C01FF    move.w  #Border,d2
1 000012 3002      move.w  d2,d0          y := 0 to Border
1 000014 3202      bit1  move.w  d2,d1          x := 0 to Border
1 000016 E35E      bit2  rol.w  #1,d6          position accumulator for next bit
1 000018 B619      cmp.b  (a1)+,d3
1 00001A 5305      sls    d5
1 00001C 5305      subq.l #1,d5          d5.w is FFFE if >= LS FFFF w/ 16
1 00001E CC45      and.w  d5,d6          clear output pixel if necessary,

```

Address	Object	Statement.	
1 000020	E35F	rol.w #1,d7	advance output bit counter
1 000022	6B0E	bai.s bit4	if complete word
1 000024	51C9FFF0	bit3 dbra d1,bit2	if more bytes in this line
1 000028	51C8FFEA	dbra d0,bit1	if more lines to convert
1 00002C	4CDF06EF	move.w 1(sp)+,a1-a2/d0-d3/d5-d7	restore registers
1 000030	4E75	rts	
1 000032	34C6	bit4 move.w d5,(a2)+	store word
1 000034	7CFF	moveq #-1,d6	reinitialize bit accumulator
1 000036	51C9FFDE	dbra d1,bit2	if more bytes in this line
1 00003A	51C8FFD8	dbra d0,bit1	if more lines to convert
1 00003E	4CDF06EF	move.w 1(sp)+,a1-a2/d0-d3/d5-d7	restore registers
1 000042	4E75	rts	

end

0 errors detected.

What is claimed is:

1. A method for operating programmable computing means to illumination equalize input pixel values of an array of input pixel values characteristic of a fingerprint image so as to produce an illumination equalized array of pixel values characteristic of an illumination equalized image, including:

receiving an array of input pixel values characteristic of a fingerprint image;

selecting equalizing subarrays of input pixel values, each including an input pixel value to be illumination equalized;

generating subarray average values as a function of the pixel values within the equalizing subarrays;

subtracting the subarray average values from the corresponding pixel values being equalized to generate pixel difference values;

adding a predetermined constant to the pixel difference values to generate intermediate illumination equalized pixel values;

setting the illumination equalized pixel values equal to a predetermined minimum pixel value if the corresponding intermediate illumination equalized pixel values are less than the minimum pixel value;

setting the illumination equalized pixel values equal to the corresponding intermediate illumination equalized pixel values if the corresponding intermediate illumination equalized pixel values are greater than or equal to the minimum pixel value, and less than or equal to a predetermined maximum pixel value;

30 setting the illumination equalized pixel values equal to the maximum pixel value if the corresponding intermediate illumination equalized pixel values are greater than the maximum pixel value; and
storing the illumination equalized pixel values as an array of illumination equalized pixel values characteristic of the fingerprint image.

35 2. The method of claim 1 wherein selecting equalizing subarrays comprises selecting equalizing subarrays, each including an input pixel value to be illumination equalized and a plurality of input pixel values adjacent to and surrounding the pixel value to be illumination equalized.

3. The method of claim 2 wherein selecting equalizing subarrays comprises selecting eight-by-eight subarrays of input pixel values.

45 4. The method of claim 1 wherein generating subarray average values includes, for each subarray, summing the pixel values of the subarray and dividing the sum by the number of pixel values summed.

50 5. The method of claim 1 wherein adding a predetermined constant to the pixel difference values includes adding a constant determined as a function of noise in the fingerprint image.

55 6. The method of claim 1 wherein adding a predetermined constant includes adding a constant characteristic of an expected average illumination of the image.

60 7. The method of claim 1 wherein adding a predetermined constant includes adding a constant representative of a pixel value halfway between the maximum pixel value and the minimum pixel value.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,811,414

DATED : March 7, 1989

INVENTOR(S) : Glenn M. Fishbine et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Insert the following before line 1 of the specification:

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